OBSERVATIONS TAKEN AT DUMRAON

BEHAR, INDIA

DURING THE

ECLIPSE OF THE 22ND JANUARY 1898

BY A PARTY OF JESUIT FATHERS OF THE WESTERN BENGAL MISSION.

BY

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WITH FOURTEEN PLATES

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PREFACE.

AMONGST the numerous scientific parties which studded the zone of totality during the Indian Solar Eclipse of January 22, 1898, was one organized on a modest scale by the Jesuit Fathers of the Western Bengal Mission. The smallness of their resources and the nature of their instruments—which, from want of larger means, were for the most part of their own device and construction—necessarily greatly circumscribed their field of research. The generosity of the Maharani of Dumraon, and the kindness and good offices of Mr. C. Fox, the Manager of the Raj, enabled them to select Dumraon as their observing station. They succeeded beyond their most sanguine expectations, and are not without hope that their results may not only be of some interest to the general public, but may also add a mite of useful information to the wealth of evidence acquired to science during the last eclipse.

As a mere enumeration and technical discussion of results might, however, prove but little intelligible to the lay reader, we have introduced a few explanations deemed necessary for a proper understanding of the work accomplished. They refer to the solar constitution, to the most efficacious means applied to its study, and to the new light eclipse observations can throw on the subject.

We have thought also that a short account of the preparatory work of the party and of the instruments they used might not be unwelcome to the many friends whose repeated inquiries testify to the interest taken in our attempt.

The last chapter has been devoted to a short record of what we could

learn, up to date, of the work done at other stations. This summary, though necessarily incomplete, will help the reader to realise more fully the important place the eclipse of 1898 is likely to occupy in the annals of science. Moreover, he will often perceive in these notes a strong confirmation of some of our results and conclusions—conclusions we should have brought forward with much more diffidence had we not met with these authoritative supports.

We take this opportunity of expressing again our gratitude to our many correspondents for their interesting contributions. They will kindly accept our apology for not thanking them here by name for the large number of valuable communications we have received.

I must also acknowledge my indebtedness to Rev. C. De Clippeleir, S.J., Director of St. Xavier's College Observatory, and head of our party, and to Rev. H. Josson, S.J., both of whom had so large a share in the working out and discussion of our results. My heartfelt thanks are also due to those who so kindly rendered me invaluable assistance in the getting up of the book.

V. DE CAMPIGNEULLES, S.J.

S. JOSEPH'S COLLEGE, NORTH POINT, DARJEELING:
June 21, 1898.

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OBSERVATIONS TAKEN AT DUMRAON

DURING THE

SOLAR ECLIPSE, JANUARY 22, 1898.

CHAPTER I.

BEFORE THE ECLIPSE.

THE more intimate the connection which modern researches seem to establish between the laws governing Solar Physics, and those of meteorological and kindred phenomena, the greater the importance of whatever may add to our sum of knowledge on that interesting subject. Gigantic as are the strides science has made in this direction during the last thirty years, many are the problems still unsolved, even in matters concerning parts of our luminary daily scrutinised by careful observations: such is the photosphere, and, since the admirable spectroscopic discovery of Dr. Janssen and of Sir Norman Lockyer, such also is the chromosphere.

But if constant study, seconded by all the powerful means modern science puts at the observer's disposal, has not as yet succeeded in unravelling the mysteries that lie within our ken, what shall we say of those more than two or three millions of miles of cosmic matter which the corona and its adjuncts show us as surrounding the Sun, and which alone a total eclipse can reveal to our eyes? Few and far between are the glimpses we are granted of the contents of those vast fields of space: precious are the instants during which all the condensed forces of science unite, to try and snatch a page from the still unknown chapters of the book of Nature. Partial success has often been the reward of these

intelligent and energetic efforts; but the time at the astronomer's disposal is all too short to obtain a complete triumph, and the attack has to be renewed, again and again, whenever a favourable opportunity occurs. This explains the flurry of excitement that the approach of a total solar eclipse produces in the scientific world, and the eagerness and enthusiasm with which the devotees of science try to be ready at any cost for the coming struggle.

The eclipse of 1898 was no exception. Indeed, the interest it awakened was all the keener owing to the bitter disappointment caused to many by the inclement state of the weather in 1896. It is true that, in a few exceptional cases, as for example at Novaya Zemlya, more favourable circumstances had allowed of new and old weapons, cleverly handled, succeeding in slightly forcing open the leaves of Nature's jealously guarded volume: a few words were deciphered, a few lines glanced at, and the possibilities they revealed, or suggested, did but increase the anxious ardour of expecting astronomers for a more general and concerted assault on Nature's hidden treasures. The much longed for opportunity was offered them this year: and from England, America, and even young progressive Japan, expeditions converged towards India, reinforced by numerous Indian parties, and numberless independent observers.

The Jesuit Fathers of Bengal, who direct two important educational establishments and possess a Solar Observatory, could not remain indifferent to the general scientific movement, and a party of nine was organized, under the leadership of Rev. C. De Clippeleir, S.J., Director of the St. Xavier's Solar Observatory. The other members of the party were the Revv. E. Francotte, S.J., H. Josson, S.J., J. Vial, S.J., from St. Xavier's College, Calcutta; Revv. F. X. De Wachter, S.J., F. Peal, S.J., L. Van Hoeck, S.J., V. de Campigneulles, S.J., from St. Joseph's College, North Point, Darjeeling; and Rev. C. Vandendriessche, S.J., from St. Mary's Seminary, Kurseong. They, later on, received the kind assistance of Surgeon Lieut.-Colonel R. D. Murray, of Messrs. A., R. and L. Lehuraux, and of several native gentlemen. The post selected was the Bhojpore Bungalow, near Dumraon, a railway station close to Buxar, Behar, where through the generosity of H.H. the Maharani of Dumraon, and the kindness of Mr. C. Fox, the Manager of the Raj, they were entertained during their stay.

Dumraon had over Buxar the great advantage of being several miles nearer the central line, the Bhojpore Bungalow being less than a mile and a half distant from it. This station had also been preferred by the party sent by the Photographic Department of the Survey of India. The true bearings of the place were furnished, with great kindness and exactitude, by the Survey Department.

To contribute, according to their very limited resources, to the solution of some of the solar problems which occupy the scientists of the day, the party had with them two telescopes, for direct ocular observations, and five photographic apparatus: three for photographs of the corona, and two for spectroscopic photography. One of the latter was a prismatic camera, the other had a concave two-inch grating. Moreover, a time-registering apparatus, built on the principle of Father Secchi's Meteorograph, recorded with great exactitude the exact moment of each exposure. To these must be added the usual fittings for meteorological and photometric records, sketches of the corona and star observations. Left almost exclusively to their own means and devices for the construction and adjustment of their instruments, the members of the party were necessarily heavily handicapped, and had to confine their efforts to observations of short individual duration not necessitating the use of clock-work. Their best thanks are due to the various Departments of the Survey of India for the valuable help they so ungrudgingly afforded them.

PROGRAMME AND INSTRUMENTS.

A short description of the apparatus used may not be unwelcome to those of our readers who took an interest in the matter.

No. 1 CAMERA.

This camera, destined to secure details of the inner corona, had a lens of 52 in. focal length, stop: F/32. Barring some slight improvements in the slide-holder, it was the identical instrument used, with good results,

during the annular eclipses of 1890 and 1894. The lens is secured at one of the extremities of a broad brass tube 8 in. in diameter, at the other end of which is fixed a narrower telescopic elongation, carrying the slide-holder.

The tube is fixed, lens downwards, parallel to the axis of the Earth, and receives light from a silvered mirror, fixed on the same stand, and equatorially mounted. The mirror is manipulated by means of two long hand rods with their knobs near the slide-holder. The slides are for quarter plates, they are double ones, and two pictures can be taken on each plate. The exposures were given by hand, and were entrusted to an assistant acting on instructions received from the operator. This camera was also intended to take a series of eclipse photographs before and after totality. All through, in this apparatus as well as in the others, the plates used were Wratten and Wainright's, mostly Drop shutter specials. The various times of exposure were successively: 1° instantaneous, 2° half a second, 3° one second, 4° two seconds, 5° instantaneous, and so on through the series.

No. 2 CAMERA.

Possessed of a particularly good and clear Ross' lens, focal length 15 in., stop: F/10, this instrument, a square camera, was destined to supplement and complete the work of No. 1 and No. 3, and to take numerous photographs, varying from instantaneous to three seconds. Its plate-holder was special: it consisted of a flat circular metallic box, in which an excentric hole faced the centre of the lens. The plate was carried on the revolving back, in such a way as to allow of eight successive exposures. The click of a spring catch indicated that the required angular displacement had been obtained, and an automatic stop prevented any further motion after the taking of the eighth picture. The box had then to be replaced by another, an operation which was the work of a few seconds. Three boxes were in readiness. The instrument was pointed to the Sun, and possessed slow and rapid altazimuth motions. The exposures were given by hand, as in the case of No. 1. A finder helped to keep the Sun in the centre of the field.

No. 3 CAMERA.

No. 3 camera was intended to record further extensions of the corona, at the expense of inner details. The focal length of its lens was 22 in., stop: F/7. Its body was a wooden square tube, with a slide-holder identical with that of No. 1. Like No. 2, it was pointed to the Sun, and had a support with slow and rapid motions. Hand exposures, varying from instantaneous to two seconds, were given to the plates by an assistant. A small telescope, whose eye-piece was replaced by a piece of ruled ground glass, acted as finder. The double slides were five in number.

PRISMATIC CAMERA.

The prismatic camera consisted of a direct-vision spectroscope with a train of five prisms, used in connection with the back lens of a Dallmeyer's triplet. The combination gave a very bright and clear spectrum, measuring $3\frac{1}{4}$ in. from *b* to a little beyond K. This instrument was also pointed to the Sun, but had no slow motion. The slide-holder, for the rest similar to those of No. 1 and No. 2, had a slit a little bigger than the spectrum given, so that, by mere hand-shifting of the slide, six spectra could be photographed on each plate. Two double slides were attached to the apparatus. Its finder was similar to those of No. 2 and No. 3, the centre of the glass corresponding to the centre of the field.

GRATING CAMERA.

In this instrument, the spectrum was given by a 2 in. Rowland's concave grating, having 14,438 lines to the inch, and a radius of six feet. Of two square tubes, hinged under the grating, and forming the body of the camera, the first, directed towards the Sun, furnished light; the other received the spectrum, and carried the plate-holder. This was similar to the holder of the prismatic camera, but half-plates were used, four spectra being taken on each. Two double slides were prepared, and the exposures were given by hand, as in the other instruments. The spectrum obtained was fully a foot in length, and was photographed in two portions, by a mere hand-shifting of the photographic tube. The whole apparatus rested

on a frame, on which it could move round a pivot placed under the grating. This frame was inclined, and hinged at the lower end to a horizontal support, and received its slow motion from hinged sliding frames, actuated by a strong iron screw, made at the workshop of the Mathematical Instruments Department.

FIRST TELESCOPE.

The first telescope was a 3 in. Steinheil on a Cook's equatorial, carefully adjusted on a substantial stand. It was intended for observations of the four contacts, and other ocular observations during the whole duration of the eclipse.

SECOND TELESCOPE.

The second telescope, a very clear 4 in. instrument by Cook, but without equatorial mounting, was intended merely as a check on the results obtained through the first in the observation of the first and the last contacts.

TIME REGISTERING APPARATUS.

As the photographs to be taken were many, and a knowledge of the exact moment of their exposure would be wanted for their subsequent study, it was thought useful to devise a recording apparatus, which would dispense with the need of a special time-keeper for each instrument. The recorder was a papered wooden board, sliding between vertical guides, and acting as weight to a clock-work. In front of the board were six numbered pencils, mounted on springs, on a transversal piece fixed on the guides. The first five represented the five photographic cameras, and whenever an operator announced an exposure, by proclaiming the number of his instrument, the time-keeper gave a punch with the corresponding pencil. The sixth pencil was under the control of the member of the party acting as time-teller. His duty was to notify the time every tenth second, counting from the signal given at first internal contact, and to give simultaneously a punch with the pencil. The second beats were given him by a carefully regulated metronome. This precaution was taken as a check and remedy to inexactitudes resulting from possible variations in the rate of descent of the board. As the space between two

successive dots always corresponded to ten seconds, the time of exposure of a photograph denoted by a punch of similar altitude on the board could always be ascertained within limits varying only by tenths of a second. A lateral counterpoise regulated the fall of the board, which at the beginning proved too rapid.

PHOTOMETRY.

A contrivance, by means of which successive small portions of a photographic plate received instantaneous exposures at regular intervals, was made use of, to record actinic variations through the whole duration of the eclipse.

METEOROLOGY.

Two very sensitive thermometers, which had been previously carefully compared with the Kew standard, were used. One of them was exposed to direct solar radiation, the other kept, with good exposure, in the shade. They were consulted at regular intervals. The bulbs of these instruments were not blackened, but a black-bulb radiation thermometer was also employed.

A good aneroid was used to mark any irregularity of atmospheric pressure.

SKETCHES.

Two members of the party, detailed for sketch drawing, had before them pieces of cardboard covered with dead-black paper, on which white concentric and equidistant circles and orientation lines had previously been traced. The inner circle represented the lunar disc, the others being separated from it and from each other by distances equal to a lunar radius. The draughtsmen were instructed to bandage their eyes, at least ten minutes before totality.

OTHER OBSERVATIONS.

The map prepared by the Survey Department of India was made use of for stellar observations.

Surgeon Lieut.-Colonel R. D. Murray kindly volunteered his services for colours and kindred observations.

DISTRIBUTION OF THE WORK.

The work was distributed as follows amongst the members of the party, who, thanks to local help, numbered nineteen :—

1.	*No. 1 Camera* . . .	Rev. V. de Campigneulles, S.J. Rev. J. Vial, S.J. Babu Gunput Roy.
2.	*No. 2 Camera* . . .	Rev. E. Francotte, S.J. Babu Paltu Prasad.
3.	*No. 3 Camera* . . .	Rev. L. Van Hoeck, S.J. Babu Shiva Prasad Pande.
4.	*Prismatic Camera* . .	Rev. C. Vandendriessche, S.J. Babu Kailash Prasad.
5.	*Grating Camera* . . .	Rev. C. De Clippeleir, S.J. Babu Satish Chandra Roy.
6.	*Equatorial*	Rev. H. Josson, S.J.
7.	*4-inch Telescope* . . .	Rev. V. de Campigneulles, S.J.
8.	*Time Registering Apparatus*	Rev. F. X. De Wachter, S.J. Mr. L. Lehuraux, *Time-teller*.
9.	*Meteorology and Photometry*	Rev. E. Francotte, S.J.
10.	*Sketches of the Corona* .	Rev. F. Peal, S.J. Mr. R. Lehuraux.
11.	*Other Observations* . .	*Stars*: Mr. A. Lehuraux. *Colours, etc.*: Surgeon Lieut.-Colonel R. D. Murray.

Prepared and provided in this way, the St. Xavier's Observatory Expedition established their instruments in the compound of the Bhojpore Bungalow a few days before the momentous date. They had been preceded there by the party of the Photographic Department of the Survey of India, under the leadership of Mr. T. A. Pope, the Head of the Department. We give on Plate III. the reproduction of a photograph of our encampment. The Survey party had established their apparatus a few feet to the rear of ours.

CHAPTER II.

THE ECLIPSE.

BEFORE TOTALITY.

SELDOM has the Indian Sun, rising in all its glory in a clear sky, whose deep blue remained undimmed by the slightest cloud, been so heartily welcome as in Dumraon on January 22, 1898. No fear this time of sore disappointment as the only reward of long and patient efforts, and so, with a light heart, every one went early to his post. The short hours sped rapidly. So much was to be done, so many final touches were to be given and last precautions to be taken. 'Ten minutes more for first contact!' so sounds the first warning. The telescopes are rapidly pointed to the rim of the Sun, and the Meteorologist takes his observations. 'Five minutes more!' Nothing is heard in the breathless silence except a few scarcely muttered words; all eyes not turned on instruments are engaged in looking through binoculars or darkened glasses. Then the two observers are seen to leave their telescopes. Their time scarcely differs, and one of the observations is found afterwards to agree to the very second with the time noted by Mr. Little for the Survey party. Time observed: 0h. 32m. 55s.; time calculated: 0h. 32m. 55s.

They have scarcely left, but some sharp eyes have already discovered a dent in the solar disc. Another anxious moment, for a sudden gust of wind rises. Will it last, and interfere with the steadiness of the apparatus? But soon it falls, as suddenly as it has risen; and then actual work begins. A last full rehearsal is quickly gone through between two of the photographs No. 1 camera takes of the progress of the Moon, the photometer does its work at fixed intervals, the thermometers also are regularly consulted, while at each instrument the assistants receive their instructions for the twentieth time; and then, standing by, the operators

try to possess their souls in patience, and anxiously follow the slow and tedious gnawing of the dark orb towards the Sun's centre. One after the other, the groups of spots are hidden from view, the large central one, observed through the equatorial, requiring about eighty seconds for its disappearance.

Up to this nothing very striking had happened: a fall of temperature of a few degrees, very perceptible in full sunshine, but much less in the shade; a slight diminution of light, such as could be expected at about 5 P.M.—that was all. But now the centre of the Sun has been covered, the remaining crescent gets visibly slenderer, and concurrently light and temperature fall rapidly. As a correspondent expresses it: 'A gloomy appearance set in, and a feeling of depression seemed to be coming on.' Soon nothing but a faint luminous streak was left, reddish, or according to some, orange, especially at the cusps. 'Everything,' pursues my correspondent, 'seemed still more depressed and gloomy, and one felt as if something awful and unspeakable were going to happen.' This feeling of gloom and depression appears to have been general amongst those not too much absorbed in other matters to prevent them from analysing their impressions. 'A weird light fell on everything,' writes another from Buxar. Some compared its intensity to that of daylight seen through a yellowish fog, others to the glare of an English winter sun in a hazy sky. They may be right as to intensity, but it was not exactly a foggy light, nor was it a pale winter sunshine: it was a cold, yellowish-grey, cadaverous sort of glare, which, as some one quaintly expressed it, seemed to go through you and make your very flesh creep.

TOTALITY.

Soon, from the telescope, came the first warning for totality: 'Five minutes more!' Operators, assistants, everyone was already at his post; one scarcely dared to move or breathe. Then, at an interval of a few seconds, came in quick succession: 'Ready!—Go!' here, as in most stations, a few seconds sooner than expected. Suddenly, to the death-like

immobility of suspense succeeded a feverish activity. Nothing, however, was heard but the telling of the seconds, sounding as monotonous as a dreary death-knell, and the numbers of operators, notifying their several exposures. 'Ninety-five!—Ready for the over!' But the warning was scarcely given when it was over, taking again every one by surprise, at Dumraon as elsewhere, so that no negatives could be secured at the exact moment of last internal contact.

And this was the total solar eclipse for most of those in charge of instruments. In consequence, from the few minutes preceding totality to the end of it, I must rely, for further details and descriptions, on the reports of eye-witnesses and the kindness of correspondents. In eclipses, as in many other events, outsiders see most of the game; while the observer, all anxiety and suspense, is entirely absorbed in the contemplation, not of the eclipse, but of the back of his apparatus. Scarcely does he dare, for fear of losing any of these precious moments, to steal, when possible, a peep at the phenomenon, a mere glance, too rapid to leave more than a general impression. Even this is at times denied him, and the first sight of the eclipse he has is when he develops his negatives. I beg, therefore, to offer once more my best thanks to my numerous correspondents for their interesting communications, of which I shall freely avail myself in the rest of this chapter. To avoid confusion, perhaps the best plan will be to treat separately the different points.

THE FEW MOMENTS BEFORE TOTALITY.

From many quarters the thread-like solar crescent is said to have assumed various colours, from yellow to pink and red, passing through orange tints, according to the sensibility of the observer's eye. This effect, which was specially strongly marked at the cusps, was partly due to the smoky yellow light of the border of the disc, but chiefly to the reddish hue of the now visible chromosphere. A few, at that moment, give a dark purplish-blue appearance to the lunar disc, evidently an effect of contrast. From Ekma, south-west of Sevan on the B. N. W. Railway, a post almost on the central line, we are told that 'just before the Sun was completely eclipsed, the full orb of the Moon became well defined by a thin arc of light on the lower side.' An interesting remark about the

sharp contrast between light and shadow, just before totality, is sent from Buxar. It is compared to that produced by electric light. On the whole: slow diminution of light during the first two-thirds of the obscuration of the disc, more rapid towards the end, never very considerable; light, strange, weird, of a cold yellowish-grey.

FIRST INTERNAL CONTACT.

The first internal contact took place at 1h. 58m. 24s., and, as has already been remarked, at Dumraon as in most other stations, a few seconds before the time calculated by means of the existing astronomical tables. Concurrently with it was produced the strange luminous effect recorded by No. 1 and No. 3 cameras (Plates V. and VI.). The presence of a fringe of metallic prominences, disappearing last on the border, and several of which were very bright, may not be foreign to its formation. Our negatives, especially that of Plate V., show very clearly all the details of the phenomenon; unhappily the reproduction of the faintest among them could scarcely be hoped for. However, a close inspection of the figure may still detect a group of three diverging pointed rays emerging from near the point of contact, and repeated in inverted order and less brightly on the lunar disc, together with the luminous half-ring enclosing them. This same negative shows several more similar diverging rays of smaller size on both sides of the first three and between them. The negative of Plate V. was taken practically at the time of contact, and that of Plate VI. a fraction of a second later. The ring of this figure is proportionally much larger than that of the other. On the subsequent negatives nothing analogous is seen. This shows that the effect is due to a luminous action proceeding from the Sun's extreme border. That the cause of it is not to be looked for in instrumental reflection, or anything of the same nature, seems established by the fact that similar effects were obtained with the naked eye. We are not aware of any ocular observation of the phenomenon at the first internal contact, but very similar appearances were remarked by several lookers-on at the end of totality—a fact which makes us regret all the more the want of photographs taken at that moment. Very likely the spectators were too much absorbed in their expectations just before totality, and too dazzled

and bewildered at the sudden appearance of the corona, to notice such fleeting details. Later on, such observations became easier for them. The notes we have received on this point will be given when we speak of the last internal contact.

CORONA.

The startling impression produced on many by the bursting forth of the corona seems to have been considerable. 'All nature was wrapped in silence, and the spectacle and feeling at that moment defies description,' says a correspondent. 'The effect was simply sublime and magnificent,' exclaims another. From Ekma: 'The change to totality was very rapid, and accompanied so suddenly by the bursting forth of the corona, that we were all moved to admiration by this sublime spectacle. Indeed, the transformation was so beautiful as to evoke a cheer from many.' 'High overhead was a sight it was worth a journey of one thousand miles to see,' adds a newspaper correspondent. And so on from many quarters. There is, however, a divergence of opinion as to the appearance of the corona itself, and more particularly of its streamers. The reasons of such divergence may be of two kinds: personal, due to the relative keenness of the observer's eyes, the precautions he took, and the means of observation at his disposal; or local, and depending on the position of the station at which the observation was made, relatively to the central line. Any difference of appreciation resulting from the first causes is easily understood, and this accounts for the somewhat dissimilar sketches and descriptions received at times from the same place. The local causes of divergence are also easily explained. It is evident that the further a station was from the central line, the less central was the eclipse witnessed. Consequently the brightest portion of the inner corona was more hidden on one side of the Sun, less on the other, than in places where the eclipse was more central. As a result the long streamers and other coronal extensions paled off and shortened on one side under the vivid coronal glare, while on the other, being seen on a less strongly illuminated background, they could be followed to a greater distance. Moreover, the impressions of details left by a spectacle at the same time so wonderful and of such short duration must of necessity have been imperfect in many cases, and it is astonishing that descriptions written from

memory, even immediately after the event, should not differ more materially.

The corona proper consisted, first, of a very bright narrow circle of white light, which seems to have been unbroken, though one observer thinks that, with the aid of a small telescope, he could follow two narrow rifts down to the lunar disc. On this ring, the prominences and pinkish vapours detach themselves, and below, close to the Moon, and on different sides at the beginning and end of totality, thin ruddy arcs of chromosphere. 'This ring was so brilliant,' says an eye-witness, 'that one almost thought the eclipse was only annular, until the incomparably greater brilliancy of the Sun bursting forth again proved it had been completely obscured.'

The intensity of this light may account for the relatively small number of those who perceived the ruddy arcs, or even the brightest of the many prominences which dotted the rim of the Sun, especially near the end of totality.

Round the inner ring stretched the second zone of the corona, extending, according to most accounts, to distances varying from somewhat less than a lunar radius at the poles to about one and a half at some 45° from them. An equatorial extension was also noticed. This of course refers to the portion of the corona proper visible to the unaided eye; but our negatives show, in spite of their short exposures, that the real extent of the actinic corona was much more considerable (see Plate X.).

A description of the coronal details seen in these photographs will be found where we treat of the results obtained by the expedition. Evidently many of these details, even among those which can stand reproduction, escaped eye observation; however, something of them seems to have been more or less confusedly noticed by keen and sharp-eyed observers. An account describes the corona as 'splotchy'; an officer of the Royal Engineers compares the inner corona to a cluster of gas jets; a few remarked some more or less distinct rift-like spaces, one of which, near the south pole, appeared to extend, according to another correspondent, down to the lunar disc. Whatever may be the case, though on our plates inter-radial darker spaces correspond to those indicated, none, even on the less exposed negatives, reaches to the bright narrow ring. The curvature of the rays towards the streamers, so clearly shown on the photographs, was also observed in one case with reference to the north-eastern streamer.

The streamers, being more conspicuous and striking objects, attracted special notice, and it is about them that informations are most abundant, but even here there is a certain amount of divergence. The general impression left seems to have been that of an irregular five-pointed star with unequal rays. Their length is variously estimated. Some observers, however, saw only four streamers; very likely, judging from some sketches received, they considered as one the two occupying the north-east of the disc. These were close to each other, one of the two being a little shorter and sensibly weaker than the other. Indeed, on one of the sketches they are evidently fused into one, very broad at the base, and curving towards the east. Personally, I stole a furtive look at the corona, about the middle of totality, between two exposures. The impression left on me is that of a severally pointed figure, with five main projections; that at the south-west fully two diameters, the others unequal and shorter. One of these, somewhat longer than the others, was diametrically opposite to the long streamer. The projection at the north-west was much less bright and long than the others, and perhaps it is the one which escaped observation in several cases. I must add that my work having kept me sheltered from any glare up to that moment, I was under very favourable conditions for the observation of the phenomenon. My observation agrees very fairly with the sketches taken by members of our party, the most complete of which is reproduced in Plate IV. Of course, the draughtsmen, having kept themselves in absolute darkness for over ten minutes before totality, were enabled to discern weak extensions which naturally escaped the gaze of most of the other observers. What has just been said refers mainly to Dumraon; as to other stations, the probable causes of the various shapes observed have already been mentioned.

On the whole, the corona was very similar to those of 1886 and 1896, the resemblance with the sketches and photographs given of the latter being very striking. It showed, as might be expected, some approach to the type proper to periods of minimum activity.

COLOURS OBSERVED IN THE CORONA.

The colours perceived in different parts of the corona seem to have been very faint; indeed, many saw nothing of them. This was probably

due to the dazzling light of the innermost ring. The opinion most generally expressed is that, as a whole, the light was white with a very slight bluish tint, particularly noticed towards the extremities of the streamers. As the informations received are mostly answers to the questions drawn up by Sir Norman Lockyer, they abound on that point.

From Buxar the streamers are described as white, while another observer, very precise and complete in all the details he sends, gives them a pale mauve tint. Another saw in the corona some yellow at the south-west, the rest of it looking pale mauve. At Ekma, the corona and streamers are given respectively as a silvery white and of a whitish light, while a lady at the same station thinks the extremities were a little bluish. The corona was seen white at Dumraon, and from the same place the streamers are recorded as silver on a blue background. Beyond rosy arcs and red prominences, nothing is noted from Nagpore but white. Two observations from Jeur describe the corona as white and opal white, and the streamers as having the colour of water with a tinge of milk, or again as emitting a silvery blue light. Silvery white is mentioned at Sadhol; white and pearly at Viziadrug. A number of other observations agree with these, a very faint bluish or mauve tint being frequently mentioned, especially in the streamers.

In the corona itself, and close to the lunar disc, pink-red arcs or layers were often perceived. The tint mentioned varies evidently with personal keenness of sight and sensibility to colour. A correspondent notes that the inner circle was more yellow than the rest; another remarked a ruddy belt gradually forming; another again saw in the innermost corona some yellow and orange; while others noticed some slight pink south and south-west of the disc,[1] a little red and yellow, some orange-yellow to the south-west, a rosy rim, some yellow and orange, etc. The south and south-west, and the approach of the end of totality are frequently referred to. Very likely the eyes were too dazzled immediately after the first contact to distinguish the faint colours of those layers which are very close to the

[1] Not a few of those who witnessed the eclipse forgot that, in facing the Sun, they were looking nearly due south, and that in consequence the west was to their right and the east to their left. For instance, the brightest prominence is constantly noted as seen on the western instead of the eastern border of the Sun. The same remark applies to the points of contact. The Moon advanced on the solar disc from the south-west, not from the south-east.

disc, before they were themselves eclipsed. They were more easily seen, near the end of totality, when getting uncovered, on the other side of the Sun.

PROMINENCES.

The largest prominences were better and more frequently seen than the ruddy vapours, especially with the help of binoculars; but here again the vivid light of the inner circle and the short duration of totality interfered with many observations. The bright excrescence seen on the eastern rim has been very generally noticed, but on account of its great brightness it appeared white to many, while others describe it as having a white base capped with glaring red. Several perceived, with the naked eye, another large red prominence on the same side but a little higher up, and three bright ones, close to one another, smaller, and almost diametrically opposite to the first mentioned. The darker spot seen on the left-hand side of the sketch (Plate IV.) represents the red prominence. Another of good size was also detected, through binoculars, on the south-western rim, near the end of totality. The photographs taken by our party show them in large numbers, though none are of any considerable height. Many, and especially those which, even on the negative, cannot be seen without magnifying power, have been obliterated in the process of reproduction, but Plate II. fairly shows the brightest of those visible shortly after the first internal contact. Towards the end, a whole string of them, amongst which was a fine red one, appeared in the neighbourhood of the point of last internal contact. A correspondent whose sight must be remarkably keen, and whose small telescope must have been particularly clear and powerful, mentions darker spots amongst the red of this last prominence, and of the largest one. If this is not an optical illusion, he must have confusedly perceived some of the less luminous spaces intervening between their filamentous and flame-like constituents. It is worthy of notice that the most important prominences recorded on the negatives occupy the same position as the streamers. This seems to point to a similar *locus* of origin.

Not a few make mention of having observed in the lunar disc strange bright notches. These apparent indentations were mere phenomena of

diffraction, due to the bright light of several of the prominences, to which they correspond in position. Several of these apparent notches are represented on the sketch.

END OF TOTALITY.

The last internal contact came so unexpectedly that it was missed at the telescope. As the first, it was some seconds in advance of the time generally assigned for it, and took everybody by surprise. In consequence, it was impossible, as we have already said, to take pictures of the eclipse at that precise moment, and to make photographically sure of the repetition of the curious phenomenon recorded at the beginning of totality. Happily, eye observations came to the rescue this time, establishing the fact that the first effect was due to external causes, and not to any defect or particularity of the apparatus. Appearances very similar to those reproduced on our negatives (see Plates V. and VI.), have had several ocular witnesses. At Buxar, an observer whose experience in these matters gives a special weight to his testimony, saw luminous rings surrounding the first visible bright point. These circles had most of the prismatic colours. The phenomenon was of extremely short duration, and very similar to what is shown on our plates, which were submitted to his inspection. This agrees fully with an observation another eye-witness made at Dumraon: 'The blazing out of light at the end of totality,' he writes, 'was a wonderful sight, and was accompanied by prismatic lights, which may, or may not, have been merely the effects of the blaze on one's own eyes.' That the impression was not a mere optical illusion is shown by the pictures obtained at the beginning of totality. We received several other informations which seem to point in the same direction, but unhappily what the observers really mean is not always very obvious.

FRINGES.

The luminous fringes and oscillating shadows travelling along the ground and across the horizon, which generally accompany the disappearance and reappearance of the Sun, escaped observations at most stations, though many a white sheet was spread upon the ground for their reception.

When the phenomenon is well marked, these fringes consist of alternating bands of light and shadow, the luminous portions of which frequently exhibit various tints. Pink, purple, yellow, orange and red were noticed in those of the eclipse of 1869, which seems to have been a record, so far as fringes are concerned. They oscillate rapidly, pretty much as the ripples produced on a sheet of water by the fall of a stone or by a slight breeze. Before totality, they move so as to become ultimately tangent to the solar disc at the point of contact, and start from that direction on the other side at the end of totality. The phenomenon, though observed with various intensities all through the zone of totality, is better seen near the limits of that region, or even a little beyond them.

In the few cases in which anything of the fringes was observed this year, they were too faint to show any colour, and consisted of weak alternating streaks of faint shadows. At Dumraon, so far as I know, only the member of our party in charge of the Grating camera noticed anything of them. The manipulation of his instrument necessitated his turning his back to the Sun. A hazy sky, or the transit of light transparent clouds before the disc, would have been fatal, or at least highly prejudicial, to his work. He was at his post, waiting to start work at the 'Ready' a few seconds before the 'Go,' and anything of the kind was far from his thoughts when, to his dismay, he saw, projected on the whitish-yellow ground he occupied, slight, ill-defined shadows rapidly following one another, like those which smoke or light vaporous masses swiftly crossing the surface of the Sun would have produced. He anxiously turned round, but the sky was as pure as ever; not the smallest cloud on its clear expanse: the shadows, however, went on passing up to the time of totality.

The phenomenon was noted also through their instruments by members of the Viziadrug and Jeur parties, who were taking ocular spectroscopic observations. At Buxar, Mr. Johnson, a member of the astronomical party stationed there, who was specially instructed to watch the fringes, observed them two minutes before totality, travelling W. S.W. to E. N.E.

At Nagpore fringe observers seem to have been equally successful. An account we received shortly after the eclipse mentions that, a little

before the complete disappearance of the Sun, 'what looked like undulating waves of mist were apparent across the horizon'; while the Nagpore correspondent of the Calcutta 'Statesman' writes that he and his party observed them on white sheets, both before and after totality. I cannot do better than reproduce his own words: 'Some one calls out, "Oh! look at the sheets!" And lo! the mysterious shadow bands are dimly trembling on the white expanse, then growing bolder, and rippling towards the Sun, like the quivering lights and shades from the surface of a stream reflected under the arch of a bridge.' Then, at the end of totality, 'Now it is over! the shadow bands are quivering and rippling still.'

That so many saw nothing of them can easily be explained. Atmospheric conditions, and the situation of a large number of the lookers-on, were unfavourable to the observation of a phenomenon so faintly perceptible as the fringes of this eclipse, especially as the attention of many must have been fully absorbed in the expectation of totality and the effects produced by the sudden reappearance of solar light. Moreover, it is to be feared that, on this point as on many others, not a few expected too much. They wanted striking, almost violent effects, as the correspondent who complainingly writes about the Moon's shadow, that he saw 'no solid wall of darkness sweeping along.' Add to this that most observers took up a position as near as possible to the central line where the phenomenon is weakest.

Few reports reached us from places not far removed from the limit of totality. We have seen, however, that at Nagpore, much less central than Dumraon, the fringes were observed. Several accounts from St. Joseph's College, North Point, Darjeeling, ninety-one miles from the central line and sixty-nine from the limit of the zone of totality, constantly agree in their description of a singular appearance perceived about the time of the greatest phase, and which seems very akin to fringes. According to one of the observers, at that moment long bright rays shot forth from the region of the cusps. The lower rays were much longer than the upper ones, in fact were lost in the hills which shut in the horizon, but all had a strong undulating motion. Another compares them to ripples caused by a stone thrown into the water; and this is the description given by several others. Beyond this undulating or rippling

motion, another, to and fro and very rapid, is mentioned by several eye-witnesses. 'It looked,' says one of them, 'as the rays shot forth by a series of electric lamps rapidly turned on and off at intervals.' Some observed what they call a kind of prismatic colouring in the rays: red, blue, and doubtful yellow. 'The rays,' adds another, 'seemed to come from behind the Sun altogether, shooting forwards and backwards.' Though clouds were numerous, the Sun was perfectly free from them at the time of the greatest phase, but, towards the horizon, they formed a dark grey screen most favourable to the projection and perception of these luminous effects. A projection of the shadow bands on that dark background seems a not unlikely explanation of the phenomenon, in spite of the sixty-nine miles separating Darjeeling from the zone of totality.

These rays were not the only ones perceived; others much brighter and shorter were also seen along the convexity of the crescent. They were much more closely packed than the others, so close in fact that they seemed to form a continuous arc near the Sun's border. At Darjeeling, the Sun was eclipsed to a considerable extent, sufficiently to make a notable portion of the thin remaining crescent show red and yellow. In fact, thirty-one thousandths of the solar diameter remained visible, the greatest breadth of the crescent being then 59·54″. Could not these last rays, and to a certain extent part of the longer ones, have been caused by a slight and confused perception of the corresponding portion of the corona? It was seen in most stations some time before absolute totality, in spite of the still great intensity of the diffused light, and the directions indicated for the long rays at the two cusps, together with their relative position, correspond exactly to those of the long south-western streamer and to the lowest of those observed at the north-east. One of my correspondents, having an opportunity of seeing the coronal sketch drawn at Dumraon, remarked that if the north-western half of the drawing were to be cut off, the portion left would give a very fair idea of what he saw; only, at Darjeeling, things were less bright and well defined. Of course the aforesaid supposition could not stand for an explanation of the undulating rays seen projected on the cloud screen, but these could still be referred to the fringes. The phenomenon lasted, with different degrees of intensity, a little less than five minutes—as long, in fact, as the cusps remained very attenuated. It may be noted that the Sun at Darjeeling

was then under the same conditions as in central stations about $2\frac{1}{2}$ minutes before or after totality, the breadth of the crescent being a little below 60″. There are instances of the full lunar disc being photographed on a background of coronal light several minutes after the end of totality, and some of our own negatives record prominences and more or less large portions of the corona as much as half a minute after last internal contact. One of them, reproduced in Plate XI. fig. 1, and taken ten seconds after the end of totality, gives the corona almost as extensively and clearly as the photographs taken during totality.

THE MOON'S SHADOW.

The rapid and visible advance of the Moon's shadow over the surrounding country is often another of the striking spectacles accompanying the disappearance of the Sun in a total eclipse. The appearance is then that of a huge dark cloud, proceeding at a vertiginous speed; but the state of the atmosphere has much to do with the intensity of the phenomenon. A hazy sky is favourable to it, whilst in a pure and clear atmosphere, like the one which obtained this year over the zone of totality, the effect is considerably weakened. For instance, last year, at Vadso and the surrounding posts of observation, though clouds prevented any sight of the eclipse itself, the swooping down of the shadow was strongly perceived. 'It was almost felt,' as Sir Norman Lockyer expresses it. This year the sky was remarkably clear, and very few, even amongst those in particularly good situations, noticed anything of it. An elevated station, or one presenting to the observer an extensive horizon, is the most favourable. It is for this reason that from Viziadrug the shadow observers were sent out to sea. They, however, perceived the phenomenon but very faintly. At Jeur also, the shadow effects noted by special observers were of the faintest kind. A gentleman who occupied an elevated point of vantage not very far from Buxar, writes that he saw the coming of the shadow from a distance of about four miles, but not strongly marked. As a rule, however, few inland saw anything of it, and so far as Dumraon is concerned, I am not aware of anyone having remarked anything of the kind. To borrow the sentence of a newspaper correspondent, 'You felt that the shadow had

come, but you did not see it coming.' It must be added that at Bhojpore Bungalow the horizon was very limited on account of trees and embankments.

OBSCURITY.

The eclipse of 1898 has been fitly described as not a dark eclipse; and this has been the cause of great disappointment People seemed to have made up their minds for midday darkness, and darkness they wanted, and considered themselves as cheated of their due when mere twilight was doled out to them. A little reflection, however, could have taught them that, in an eclipse like the one of this year, great obscurity could not be expected. On account of the relative distances of the Sun and the Moon from the Earth at that date, the screen cutting off from us the solar rays was very little larger than our luminary itself: the apparent diameter of the Sun being 16′ 14·83″, and that of the Moon at Dumraon, at the present time of totality, 16′ 35·01″. In consequence, much diffused light could still reach us. For the same reason, a large amount of the innermost corona remained uncovered. Now the illuminating power of this innermost circle is far superior to that of the full Moon, and much of the greater obscurity perceived in eclipses of longer duration is due to its disappearance. As matters stood, the diminution of light, though very perceptible, does not seem to have been anywhere very considerable. Here again recourse must be had to informations received from others, operating observers having neither time nor opportunity to busy themselves with the secondary phenomena. However, this much we can say, that at Dumraon, at any rate, the fall of light was not sufficient to interfere with the working of any apparatus, not even with the reading of the thermometers to tenths of degrees. More or less the same apparently was observed at all other stations, and the general note sounded is, Darkness much less than expected. It has been compared to that of daylight at about 5½ o'clock, or a little later, at that season of the year. Reading, even of small print, was at no time really difficult in the open air.

STARS OBSERVED.

As a natural consequence of the relatively strong illumination of the sky, very few stars were seen. Venus was generally observed as much as

nine or ten minutes before and after totality. At Dumraon and different other stations several spectators saw Mars and Mercury, but rather faintly. Two others, from the same post of observation, mention another star which, by the position they assign to it, cannot be other than Fomalhaut. Some, however, leave us in the dark as to what they noticed: a correspondent, for instance, saw Venus and three other faint stars, but which or where is not said. Very likely they are the three mentioned by others.

ASPECT OF THE SKY.

The appearance of the sky is variously described as a slate colour, a dull greyish-blue, a dull purple colour overhead. The horizon is very generally said to have assumed a purplish hue, surmounted by a bright yellow or yellowish-white belt. No mist nor clouds were noted anywhere, and consequently no halo or cloud irradiation. At Dumraon, the atmosphere remained during the whole eclipse particularly bright and clear, but a very bright yellowish light surrounded the horizon. At Nagpore and elsewhere the horizon was purple, surmounted by a yellowish belt.

CHANGES IN COLOURS AND SCENERY.

Some slight but curious colour effects were noted. Generally the prismatic colours remained distinguishable, though some change of tint took place in the purple, and the yellow looked duller. The scenery is described from Nagpore as if looked at through a smoked glass, and the waters of a lake are said to have looked black. Even at places far removed from the central line, special colour effects were remarked. From Simla, for instance, 559 miles off, a correspondent writes that 'the appearance of the light during the eclipse was very beautiful, a soft violet-grey diffusing itself over Jakko and the surrounding hills, approaching more nearly the twilight in Western Europe than anything I remember having seen in the East.' From Calcutta eye-witnesses report that through blue spectacles the crows looked green, and that many things assumed a dull yellowish tint. At St. Joseph's College, North Point, Darjeeling, white objects, such as the shirts of the boys on the playground, looked yellow, while faces took a purplish tint. On the whole, as was to be expected from

the slight decrease the light underwent, the effects on colours and scenery were not strongly marked, and many, who looked for phantasmagoric transformations were disappointed.

EFFECTS ON THE ANIMAL CREATION.

Many posts were so situated that observations on wild animals were scarcely possible, and, as a rule, domesticated animals are less easily disturbed than others under such circumstances. Hence our informations on this point are scanty. Personally, they are restricted to the crowing of a cock at the end of totality. The ubiquitous Indian crow, however, comes to the rescue. A gentleman who witnessed the eclipse at Dumraon, and sent us a useful and detailed report of the various items he personally observed or could gather from others immediately after the event, records the following: 'Just before totality the frogs began to croak and the cocks to crow, and the crows began flying in bodies to their roosting-places. It was amusing to see these crows all flying back again, just after totality, with much cawing, as if they were explaining to each other how they had made a mistake.' They behaved much in the same way elsewhere. Mention is also made of a few bats, flying-foxes, and of an owl that began flying. For further information on the subject, I shall have recourse to the notes of a youthful Nagpore correspondent whose turn of observation seems to give fair promise for the future. The party to which he belonged had taken their station on the banks of a lake. 'At this time,' says my young informant (the time of the apparition of fringes), 'the birds and the cattle seemingly noticed a change. A batch of ducks on the lake seemed restless, while a herd of goats huddled themselves together and eventually sat down. Some cattle also that were browsing started moving, as if they thought it was time to go home; while a flock of geese flew overhead, apparently making for their roosting-place. Then the ducks on the lake made for the edge of the water among the reeds. The fish now showed visible signs of agitation, coming up to the surface and disappearing, and the smaller ones leaping out of the water.'

AFTER TOTALITY.

The totality over, the rest of the eclipse presented but little interest up to the moment of last external contact. Indeed, the attention this last phase attracted was far inferior to that given to the first: the reaction after the tension and anxiety felt during totality can easily account for it. Some photographs of the partial eclipse were taken with No. 1 Camera, and the observers patiently waited for the last contact of the eclipse, which took place at 3h. 16m. 32s., several seconds before the time anticipated: a recurrence of what has already been noted about the second and third contacts.

That so many independent calculations were at fault by several seconds, and all in the same direction, especially with reference to the two internal contacts, giving them a few seconds later than the time at which they actually took place, and assigning to the totality a duration greater than the actual one, cannot be the result of personal errors, but points to some still uncorrected defect in the astronomical tables.

The following table gives the times observed both by Mr. C. Little, Professor of Mathematics, Presidency College, Calcutta, who took them on behalf of the Survey party, and by our own observers, together with those given by computation.

Contacts	Computed			Our observations			Difference	Observations of Mr. Little			Difference
	h.	m.	s.	h.	m.	s.	s.	h.	m.	s.	s.
1	0	32	55	0	32	55	0	0	32	55	0
2	1	58	30	1	58	24	– 6	1	58	25	– 5
3	2	0	10	[2	0	3	– 7]	2	0	4	– 6
4	3	16	48	3	16	32	–16	3	16	33	–15

As may be seen, both the observations of the first contact exactly agree with the calculated time. Our observation of the second differs by one second from that of Mr. Little, but the spectrum obtained at that moment by the prismatic camera shows that the 'Go' was given nearly a second too soon. The fear of losing the important photographs of the beginning of totality induced the observer to give the signal before the last of the Baily's

beads he noted in the telescope had completely disappeared. This easily accounts for the slight divergence. Nobody regretted his decision, as it was the means of securing several highly interesting photographs. The third contact, as has already been said, took everyone by surprise. The length of totality deduced by interpolation from the Nautical Almanac table was 99·7 sec.; calculation gave 100·8 sec.; while the actual duration, according to Mr. Pope, was 98 sec. Mr. Little obtained 99 as the 'result of a hurried glance at the chronometer.' The last observations again differ by only one second, a very satisfactory coincidence considering the difficulty there is, in presence of the violent agitation of the border of the Sun due to atmospheric action, in ascertaining to the very second the exact moment of the last contact.

A remarkable feature is the evident progression in the divergence between the results obtained and those computed; this naturally points to a common cause: its nature remains to be determined.

CHAPTER III.

SOLAR PHYSICS IN CONNECTION WITH ECLIPSE WORK.

A RAPID glance at the most important facts known about the constitution of the Sun may help our lay readers to understand some among the many problems of solar physics which at the present time absorb the attention of physical astronomers.

The solar world, at least that part of it which can be reached by the means of observation at our disposal, may be divided into three main regions.

1. The **Photosphere**, the visible bright envelope of the globe, from which we receive the greatest part of our heat and light.

2. The **Chromosphere**, a gaseous incandescent shell, seen only under special circumstances or by means of appropriate instruments.

3. The **Corona**, or those extensive and so far little known surrounding spaces, occupied by cosmic matter, and of which the brightest portions become visible during total eclipses.

Each region has its own characteristics, and the various phenomena observed in them point to a considerable difference in their constitution. On all three, but especially on the chromosphere and the corona, much light can be thrown by a total eclipse, on account of the facilities it affords for the isolation of some important luminous manifestations of a weaker nature from others more strongly marked, by which they are more or less obliterated under ordinary circumstances.

1. THE PHOTOSPHERE.

THE INNER GLOBE.

The physical state of the inner portion of the solar globe, which totally escapes ocular observation, is practically unknown to us. Deduc-

tions drawn with a higher or lower degree of probability, from the study of surface phenomena, are the limits of our knowledge.

Though opinions are still divided on this point, the weight of authority and observation is strongly on the side of a fluid constitution, most likely both liquid and gaseous, under a high degree of pressure. One of the strongest arguments in favour of this hypothesis is the unequal velocity of revolution of the solar surface at different latitudes. It follows from the comparison of long series of spot observations that though the actual velocity is more rapid, the angular displacement is slower about the solar equator than near the polar regions: a state of things which can only be explained by the presence of a fluid envelope of such thickness that any further supposition of a small central solid nucleus seems useless. Moreover, this fluid state as well as the inequality of motion are in perfect accordance with the generally received ideas about the formation of our solar system. The practically constant emission of light and heat presents also a serious objection to the existence of a solid mass of condensation forming any notable portion of the solar globe. The foregoing does not, however, exclude the possibility of the existence of numerous solid particles suspended as dust in the fluid mass.

Several other arguments could be brought forward in support of the fluidity of the Sun, but as eclipse observations do not directly throw much light on this point, their discussion would be beyond the scope of this work.

PHOTOSPHERIC SURFACE.

It is with the photosphere, or the incandescent, luminous and visible envelope of the solar globe that we are concerned for the present, as we are in a position to apply directly to the investigation of its state many of the powerful means modern science puts at our disposal.

The spectroscope is the best instrument placed in the hands of observers for these studies. Its nature and methods will be briefly sketched in another chapter; here we are merely concerned with the facts and probabilities, almost amounting to certitude, given to us as fruits of researches made with its help.

The powerful telescopes of our days are also precious auxiliaries, and through their means fields have been thrown open to scientific investiga-

tions the existence of which was scarcely suspected before. Viewed under the strong magnifying power of large instruments, the surface of the Sun presents a peculiar appearance. It looks reticulated, as if grains of irregular shape and size were thickly strewn over a slightly less luminous background. This appearance is pretty well that which the Earth, surrounded by irregular masses of vapours and strongly illuminated, would present from a distance. It is a new argument in favour of the theory of fluidity; while the results furnished by the spectrum analysis of the masses themselves militate still more forcibly in the same direction.

On this chagrined background are dotted, without apparent order, darker spaces of various sizes and forms, known as solar spots, and bright, irregular, ramified structures, to which the name of faculæ has been given. There are good reasons for believing that the granulated aspect the disc presents is due to foreshortening of flame-like masses, constituting a highly agitated, incandescent, and fluid surface.

SUN SPOTS.

Spots and faculæ, whatever may be the theory accepted with regard to their origin, result from a state of things identical with that producing the granulations. Several hypotheses, which it does not behove us to discuss in this work, are brought forward to account for their formation; but whatever may be the force by which they are generated, the following facts seem to be admitted by all: the majority of the spots have a dark central nucleus, habitually surrounded by a less obscure portion, called the penumbra; the nucleus and the main part of the penumbra are, in most cases, sunk below the highest level of the photosphere, but are surrounded by a raised rim, higher on the side towards which the spot seems to proceed. Carefully compared and revised observations, covering a number of years, show without any doubt that beyond the rotatory motion round the solar axis common to the whole surface, the spots have an independent motion of their own, both in longitude and latitude. Moreover, even a superficial study of any spot gives evidence of a considerable degree of perturbation. Their shape is rapidly undergoing modifications, they increase or decrease in size, split into fragments or

unite, and vanish altogether or appear unexpectedly even at places where no spot had before been seen. Their details, especially in the penumbra, often affect a whirling appearance, and the whole is very similar to the effect produced by violent spiroidal ejections, or by whirlpool-like absorptions, or more likely by a combination of both. The darkness of the nucleus is due merely to contrast; indeed, the light-emitting and actinic power of its darkest portions is such that extremely rapid photographic exposures are required in order that its image may not be burned. The great absorption of light which takes place in the nucleus is attested by the spectroscope. When the slit of the instrument is directed to one of them, a number of Fraunhofer's dark lines are seen notably enlarged in the spectrum. This indicates in no uncertain way that the nucleus consists of a gaseous mass cooler than the rest of the photosphere, and overlying brighter regions. These facts give special weight to the opinion which considers the spots as resulting from the condensation of ejected materials, such as those projected by prominences to considerable distances from the surface. These masses becoming relatively cooler, and consequently denser, by radiation into space, would fall back on the hotter and brighter photosphere, on the surface of which the action of their weight concentrated by increased density would produce a depression.

Spot zones.—Though the spots may, at first sight, seem scattered at random on the surface of the Sun, this want of order is only apparent. They are very rare at high latitudes, and scarcely higher than 30° from the equator in both solar hemispheres; in the mass of observations collected up to this, there is only one doubtful instance of a spot as high as lat. 50° N., and but two at lat. 45° S. They are specially produced within two zones oscillating regularly between the equator and 30° on both sides of it.

Short cycle.—The number and magnitude of the spots are subject to maxima and minima, the recurrence of which is governed by fixed laws, a period of about $11\frac{1}{3}$ years elapsing between two consecutive maxima. The minimum does not, however, divide this eleven years cycle into two equal portions, but the passage from a maximum to a minimum is very slow and gradual, requiring about $7\frac{1}{2}$ years according to De la Rue while only some $3\frac{5}{6}$ years afterwards the maximum is reached again.

Long cycle.—Beyond this short cycle there are reasons for believing

in the existence of another of longer duration. Judging from the evidence of the observations collected during the last two centuries, the length of this period seems to be from 50 to $55\frac{1}{2}$ years, or perhaps a little more. Evidently a law governing events recurring at such long intervals requires observations extending over a much longer time before it can be considered as definitely established.

Latitude variation.—The latitudes at which solar spots appear depend on the stage of the eleven years period which has been reached. Low latitudes rule at the time of minimum, but a sudden jump to higher ones is taken as soon as a general recrudescence of activity manifests itself. From that moment, though the maximum is not reached, the latitudes steadily and gradually fall again till the next minimum is attained.

Several causes, so far unknown, apparently interfere at times with the regular working of the eleven years cycle. This year, for instance, ought to have shown a marked tendency towards a minimum, in spite of which large spots, habitually a sign of greater solar activity, have been far from scarce. We shall have occasion to refer again to this irregularity when examining the results given during the eclipse by the prismatic camera.

FACULÆ.

Regions where spots are going to appear, as well as those from which they have just vanished, are often marked by bright, irregularly ramified patches known as faculæ; often too they can be found, in greater or less abundance, in the neighbourhood of existing groups. They are not, however, limited to the spot zones, but are frequently seen, even in larger number, at much higher latitudes. They are luminous ridges, raised over the photospheric mean level, and looking brighter than the surface, either on account of greater local activity, or because the over-lying gaseous masses being less in thickness, the absorption of light is not so considerable.

A more or less intimate connection seems to exist between prominences, faculæ, and spots. At any rate, their appearance in large numbers, particularly that of spots, generally coincides with notable electric and

magnetic disturbances, attested by the perturbations undergone by magnetic instruments.

Let us conclude with M. Deslandres[1]: 'The periodicity to which apparently widely different terrestrial phenomena conform themselves, and which on the other hand assimilates the Sun to variable stars, is one of the most important facts brought to light by physical astronomy. The general cause producing it is unknown, though it is probably of an electrical order, and the explanations proposed are vague or incapable of being verified. This, however, ought not to astonish us, as we are still ignorant of the causes and the nature of the various parts of the whole, viz. terrestrial magnetism, solar spots, prominences, and especially the corona.'

Many savants, amongst whom are found the names of De la Rue, Stewart, Loewy, and others equally eminent, are inclined to admit planetary action, and particularly that of Venus and Mercury, as one of the determining influences.

2. THE CHROMOSPHERE.

Height and brightness.—The name of chromosphere was first given by Sir Norman Lockyer to the relatively thin, gaseous, incandescent envelope surrounding the photosphere. Invisible to the naked eye under ordinary circumstances, it shows itself, during eclipses, in thin ruddy or rosy arcs adjacent to the dark lunar disc, at the beginning and end of totality. Its height varies with circumstances at different points of the solar surface, but it does not generally exceed 12″ of arc. The same may be said of its brilliancy, which habitually has its maximum in the region of spots.

Aspects.—To expose its various aspects, I cannot do better than borrow the words of Father Secchi, S.J.,[2] who was amongst the first to study and describe them:

'The chromosphere presents four well characterised aspects. (*a*) The first is that of a sharply defined layer, similar to the free surface of a

[1] **Deslandres:** *Observations de l'Eclipse Totale du Soleil du* 16 *Avril* 1893 *au Sénégal*, p. 53.

[2] **Secchi:** *Comptes Rendus de l'Académie des Sciences*, vol. lxxiii. p. 87.

liquid. Its brightness contrasts plainly with the dark surrounding space, and only a slight diminution of intensity is noticed near the external border. (*b*) Very often the chromosphere is bordered by a bright, short, hairy fringe; the hairs are more or less inclined, but all in the same direction. This structure is chiefly noticed between the mean latitudes and the poles. The threads are not always bent in the direction of the higher currents which carry away prominences, but such is often the case. (*c*) Sometimes, especially in the region of faculæ, the surface is so ill-defined that it is hard to say where it ends. (*d*) Most frequently the external boundary of the chromosphere is irregular, and possesses small conical and irregular appendices or flame-like projections, bent in every direction. These are rudimentary prominences, and are more frequent on those portions of the solar perimeter where the most distinct granulations are found.'

Others, and amongst them Prof. Respighi and Sir Norman Lockyer, made similar observations. We quote here some remarks of the first, reproduced by Sir Norman Lockyer[1]: 'Very seldom, and that in the region of the spots, it presents the appearance of long regular strokes, even to the summit, resembling a bright circular arch.' And again[2]: 'The height of this stratum is variable in the several parts of the solar circumference, and generally seems higher in the vicinity of the poles than at the equator; and, on rare occasions, it is found to be very low near the large groups of prominences.'

Spectrum analysis shows the chief chromospheric constituents to be hydrogen and helium at a high temperature, especially, in present circumstances, at high levels. Many other incandescent metallic vapours such as calcium, titanium, manganese, magnesium, sodium, but particularly iron, are also found in the chromosphere. These vapours are more frequently and abundantly met with in the lowest strata. The same method of investigation has brought to light the fact that these vapours are often disposed in layers, and may be present at a certain height when they are lost to sight, to appear again, however, at greater altitudes. The same may be said of the temperature of the strata. Recent spectroscopic observations tend to show that there are great variations of temperature at different chromospheric heights, and that at times the upper regions are

[1] Lockyer: *Solar Physics*, p. 586.

[2] *Ibid.*

notably the warmest. We shall not dwell here on this point, but simply call attention to the full agreement there is between such a state of things and the hypothesis of the scientists who, with M. Deslandres, consider the existence of the chromosphere as due to an electrical phenomenon, identical in nature, if not in degree, with the continuous electrical discharge that takes place in our atmosphere on account of the fall of potential at different altitudes. The much controverted reversing layer, occupying the lowermost chromospheric region, will be treated of in the next chapter.

PROMINENCES.

The prominences are gaseous-looking incandescent masses, ascending flame-like, as if from the lowest strata of the chromosphere, and projected beyond it, sometimes to considerable distances, with vertiginous velocity. Some have been observed reaching heights of over 200,000 miles. The rapidity with which they can be produced is often not less wonderful. On June 17, 1891, one of them was observed at the Haynald Observatory, Hungary, by Fr. Fényi, S.J., rising vertically as a single mass from the surface of the Sun, and ascending to the remarkable altitude of over 100,000 miles, with a speed scarcely inferior to 400 miles per second.[1] The last eclipse presented a striking instance of rapid prominence formation. The group occupying the western limb of the Sun consisted of three prominences ten seconds after the beginning of totality. Sixty seconds later a fourth one, very bright and equal in size to the others, had been formed (see Plate XIII. figs. 5 and 6). Their constitution varies, and some, particularly the brightest, contain a more or less large amount of metallic vapours noticed in the chromospheric strata, but their chief constituent is hydrogen at different degrees of incandescence. Indeed some appear almost exclusively composed of it.

The existence of these strange objects had not escaped the observation of former times. Too faint to be detected in the full light of the Sun, the

[1] In 1882, the writer had himself occasion to observe a similar phenomenon, though not on such an extensive scale. While recording solar prominences at St. Xavier's College Observatory, Calcutta, he saw a thin, spear-like, intensely bright prominence suddenly rise under his eyes, straight as an arrow. In less than three minutes it had attained many thousand miles in altitude. Unhappily, circumstances did not allow of accurate measurements. Subsequent information showed that the same eruption had been witnessed by Prof. Tacchini and by two other observers.

largest of them become visible, even to the naked eye, when the disc of the Moon screens it from the solar glare during a total eclipse. Those of sufficient height to overlap the edges of the screen are then perceived as irregular reddish masses of various brightness.

The attention of modern astronomers was first called to prominences during the eclipse of 1842, in the course of which the surprise caused, even to experienced observers, by their detection, was such that they were unable to take observations with any degree of precision. Their appearance was nothing new, but the exaggerations and inexactitudes of former eye-witnesses had prevented any attention being paid to their descriptions. As soon, however, as their existence was known to be a scientific fact, attested by such authorities as Arago, Airy and Struve, amongst others, serious investigations about their nature and origin began. Little progress nevertheless was made for some years in this new field of research; the means at the disposal of the inquirers were not adequate. The main points elucidated during this time were that prominences have a real existence and are not due to optical illusion; that they have their origin in the Sun and not in the Moon; and that, in all probability, their constitution is gaseous.

Then came the eclipse of 1868, and the great spectroscopic discovery of Dr. Janssen and Sir Norman Lockyer, through which prominences, invisible up to that time except during eclipses, became an easy subject of study, whenever the state of the atmosphere allowed of the use of the instrument. Observations soon established the fact that there is a frequent, though not necessary, connection between prominences, faculæ, and spots, indicating a similarity of origin. Their rapid formation and transformations, and their appearance, which is often shaggy, ragged and thread-like, pointed to a violent state of agitation under the action of stupendous forces. Moreover, though not limited in any way to the spot zones, as they are sometimes more frequent in other regions, prominences are observed to be similarly affected by the maxima and minima of solar activity, and the reversing of a number of Fraunhofer's rays in their spectrum shows that they consist of masses of bright, incandescent vapours, amongst which hydrogen predominates.

These first results, the fruits of patient and persevering researches, were followed by others still more startling, and it became possible not only to

study the structure and constitution of a prominence, but even to ascertain the rapidity and direction of the various movements taking place in its mass.

Theories.—The theories which seek to explain the origin of prominences are at least as numerous as those with regard to Sun spots. Father Secchi and others, with whom more recently Prof. Schœberle, of the Lick Observatory, agrees, consider them to be the result of violent solar eruptions, accompanied by powerful electrical manifestations. Their cause is variously explained. Solar heat or chemical combinations, for instance, are among the hypotheses suggested; all, however, recognise the coexistence of electrical action. M. Deslandres[1] and other recent authorities go a step further in this direction. Considerations on the varied and rapidly shifting forms of prominences, and on the frequently high degree of rarefaction of the vapours composing them, and particularly the study of their spectrum, led these writers to consider that same electrical action as the primordial cause not only of these chromospheric excrescences, but also of kindred phenomenon, such as of the chromosphere itself and even of the corona.

The spectrum of prominences gives strongly the rays proper to incandescent rarefied hydrogen, and so far as the means at our disposal go, it does not seem possible to render gases incandescent by heat alone without chemical or electrical intervention. Trials on the so-called permanent gases always give negative results, while those obtained with the others are either null or very doubtful. At any rate, the characteristic rays of rarefied hydrogen, easily produced by the current of the smallest Ruhmkorff's coil, have never been obtained by the most intense heat which we can produce, without electrical intervention. A spectroscopic observation of Prof. Hartley, on the flame of the Bessemer converter, though apparently against it, is a new argument in favour of the electrical theory. He once distinctly perceived in the spectrum of the flame of a Bessemer steel converter the hydrogen red ray; but he found afterwards that his experiment had coincided with great electrical atmospheric perturbations. It seems therefore natural to consider the prominences as having an electrical origin. Moreover, the extreme rapidity with which they appear and disappear, and their swift variations of shape on an astounding scale,

[1] Deslandres: *Eclipse Totale du Soleil du 16 Avril 1893*, p. 64.

agree better with the hypothesis of an electrical discharge than with that of the translation of ponderable matter under the mere action of an impulsive force. Let us add that this theory attributes to electricity merely the leading *rôle* in the production of the phenomenon, and does not in any way exclude the concurrent intervention of other forces.

3. THE CORONA.

The chromosphere is not the only solar envelope; beyond it there stretches, to an enormous but unknown extent, an atmosphere of cosmic matter evidently connected with our luminary. It is not at all impossible that what is called zodiacal light is due to the illumination of these cosmic masses, either by self-emitted or by reflected light. During a total eclipse, however, a phenomenon is perceived differing from it at least in appearance. Around the dark orb of the Moon there shines a brilliant circle of whitish light, which receives the name of the corona, and which is often of dazzling brightness towards its inner edge. Its shape in different eclipses varies greatly, though its general characteristics are more permanent. With reference to its principal features it may be considered as formed of two parts: 1. the corona proper; 2. the streamers.

1. **The corona proper.**—Two zones can be detected in the corona proper; (*a*) the innermost portion: a narrow, and, as far as can be seen, habitually continuous ring, the luminous intensity and actinic power of which are greatly superior to those of the full Moon; and (*b*) a more extensive zone, varying much in breadth and brightness, and seldom visible to the naked eye at distances greater than a lunar diameter from the Sun. The light which it gives is strong near the bright ring, but gradually fades off into space. Projected on the inner ring are seen the prominences and ruddy clouds emitted by the chromosphere. The outer zone is far from having a constant breadth, not only in different eclipses, but also in the several parts of its circumference. The minimum is attained at the solar poles, and the maximum in positions about 45° from them. There is also frequently a marked extension about the equatorial regions.

Its structure is peculiar, and in many places strikingly similar to that of

a large class of prominences, but on a more extended scale. It consists of luminous rays of varying brilliancy, at first straight and diverging, then entwined and curved towards one another, assuming leaf-like shapes to which the name of dahlia petals has been given. Others, branching off, are called stag-horns; others again are arched over, and have the appearance of bridges. Amongst them appear at times small less luminous masses like light clouds. Near the poles, and sometimes at other places, are frequently seen darker spaces, from which the rays curve off as if under the influence of repulsion. These spaces have been called rifts, and now and then almost reach to the lunar disc. In the vicinity of the streamers the rays are often seen to bend towards them, as if a centre of attraction or suction existed there.

2. **The streamers.** From the corona proper, or rather from its depths, long and luminous streamers shoot forth. They are bunches of bright diverging rays, mostly straight, and of different breadths. Silvery white is their usual colour, though very frequently a dash of faint mauve or pale milky blue can be detected. Their shape and length differ much, even in the same corona, and both the state of the sky and the observer's position relatively to the central line of totality affect their appearance: they can, at times, be followed to a distance of several lunar diameters. With the exception of occasional slight variations in size and luminous intensity, and sometimes a slow but perceptible shifting round the disc, the streamers are motionless, and greatly resemble the luminous streaks seen through cloud openings at sunset. Rays have on some few occasions been observed of special brilliancy, and not like the others radiating from the disc. They generally look as if issuing from a spot marked by a particularly bright prominence. One of the most remarkable was observed during the eclipse of 1868. It was transversal, striking obliquely upwards from right to left, and appeared only two minutes after the beginning of totality. It may be seen on a very exact drawing executed at the time, and reproduced in most books treating of eclipses. Some astronomers have advanced, as a plausible explanation of these exceptional rays, the transit of a cometary mass through the solar atmosphere. In support of this view, it may be said that the cloud-like prominence from which the ray seems to emerge on Captain Bullock's drawing is suspended over the chromosphere without any apparent connection with it.

The corona can easily be photographed in its brightest parts, and the same may be said of the lowest portion of the streamers; but, up to this, attempts to reproduce these last to the very limits of their visible extensions have not been attended with complete success. These faint portions are wanting in actinic power; the corona, on the other hand, impresses the plates much more easily, even at distances where its attenuated light can scarcely be detected by the eye.

For a long time the origin and constitution of the corona remained one of the closed pages of the book of Nature. There was a lack of adequate means for the study and determination of its components, and solar physicists were left to conjectures and hypotheses resting on a knowledge of phenomena of apparently similar nature. However, since the application of spectroscopy to solar investigation, many data have been gathered, and though much still remains without adequate explanation, great steps have been made towards the solution of these interesting problems.

Before entering on a brief exposition of the main theories on the origin of the corona, it may be useful to set down, with reference to its constituents, some facts which have been established by observations taken during the eclipses of the last thirty years.

CORONAL SPECTRUM.

The coronal spectrum is multiple. It consists of a faint continuous spectrum, in which Dr. Janssen has lately detected some weak traces of dark absorption lines, and of a spectrum of luminous disconnected rays. It presents, therefore, the spectroscopic characters both of an incandescent solid or liquid, and of an incandescent vapour. The bright rays belong to various elements, such as hydrogen, helium, calcium, and, according to Mr. Pedler's observation during the last eclipse, iron in the lowest strata. There is present, moreover, a hitherto unknown substance, giving a characteristic bright ray in the green, and corresponding to Kirchoff's 1474. This ray is absent from the chromospheric and prominence spectra.

The paucity of the bright rays belonging to each substance, and consequently the great simplification of their respective spectra, indicate

a high state of rarefaction of the vapours; while the faint continuous spectrum points to the existence of solid or liquid particles. We have, therefore, in all probability, a medium of incandescent gases, in which are suspended as a fine dust extremely attenuated liquid or solid self-luminous particles, part of the light of which, however, may be due to reflection.

THEORIES.

Theories about the origin of the corona are very numerous; but the evident connection existing between it, the chromosphere and the photosphere, requires that any hypothesis put forward to explain its formation should not clash with well-established facts concerning the latter: the three must be studied conjointly.

First theories.—During the first sixty years of our century, observers of the corona had not at their disposal the powerful means of investigation which the spectroscope applied to solar analysis has placed in the hands of the scientists of the day, and their theories, though ingenious, were often mere conjectures, based on insufficient data, and necessarily inadequate. The telescope was their chief means of observation, and as the faint coronal light can scarcely stand the diffusing power of the instrument, the details seen with the naked eye disappeared. Hence astronomers were not wanting who considered the corona and its streamers to be products of light diffraction, or even mere subjective phenomena. The spectroscope, however, afforded evidence of their real existence, and new hypotheses had to be devised. A few words about the most recent will suffice.

Meteoric theory.—The meteoric theory is not precisely a new one, but it was revived and strengthened by new arguments some ten years ago It was originally put forward as a plausible explanation of the variations of stars, and was applied to the Sun, which presents several stellar characteristics. This hypothesis, put forward in 1890 by Prof. Schuster in the Philosophical Transactions, seems a development of Siemens's theory of the Sun, and among other advantages it accounts for the periodicity of solar activity.

The dissymmetry, always on the same side for the same time of the year, which the corona seems to present, is an argument in favour of

this theory, from which it would naturally follow; but the curvature of the rays in the polar regions, and the equatorial extension proper to the minimum period, remain unexplained. Moreover, no rapid independent rotation of the corona has been observed, a fact not easily reconciled with an origin due to meteoric masses possessed of considerable velocity of their own. It may be noted in connection with this, that besides hydrogen there is in the chromosphere abundant evidence of the metallic vapours of iron and of precisely the same metals that go to the formation of meteorites, so far at least as we can judge of the latter from the specimens at our disposal.

Eruptive theory.—An opinion, very widely spread amongst scientists, looks to eruptive forces as the original causes of the corona. This is the view generally taken by those who attribute a similar origin to prominences. According to them, gaseous masses are projected into space with extraordinary violence and velocity, and these, cooling down through radiation, are partly condensed into a fine incandescent dust which remains floating in the gaseous medium. The enormous extent of the corona does not present a serious difficulty, as the velocity of ascent observed in many prominences is more than sufficient for carrying the material composing them to regions distant enough to be practically beyond the sphere of influence of solar gravitation. They could then remain suspended for a considerable time, forming a kind of incandescent, self-luminous solar atmosphere. Moreover, the perpetual disturbances caused by the almost incessant inrush of new materials, could in themselves be considered as sufficient to maintain these minute particles in suspension.

The curvature of the coronal rays remains to be explained. Quite recently Prof. Schæberle, of the Lick Observatory, proposed as a solution the differences in original velocity of projection at different angles to the surface. According to him, the curved rays are portions of ellipses, a focus of which is at the solar centre. The data we possess for the present do not, however, seem sufficient to establish this point clearly; and there is always some difficulty in the admission of violent eruptions of volcanic nature originating from gaseous surfaces, such as those of the chromosphere and the photosphere. Moreover, the action of prominences themselves, which in the eruptive theory have a similar cause, offers a serious

objection. If they are merely the result of ejections, the radial velocity of their materials must necessarily decrease as the height increases; and spectroscopic observations prove that not only is such not the case, but that, in most instances, the velocity increases with the height, as if the ascent took place under the influence of a constantly applied accelerating force. Again, prominences are subject to very swift changes of form, while photographs of the inner corona, taken at different places and at intervals of two or three hours, scarcely show any change at all in the shape of the rays.

Magnetic theory.—Prof. Bigelow[1] has recourse to magnetism, and supposes the Sun to be subject to the same magnetic conditions as the Earth. The rays would then be due to a disposition of the particles of cosmic dust along the magnetic lines of force. This assumes, somewhat gratuitously, that the particles are magnetic. It is true some iron is present, at least in the lower strata, and may be spread all over as solid dust, and we know nothing of the nature and properties of the substance giving the characteristic coronal green ray; but hydrogen, calcium, and other constituents are not magnetic, at least in the circumstances under which they are known to us. The case would be different, however, as we shall see, if electricity had anything to do with those minute solid grains—with their illumination, for instance.

The drawings which reproduce the results of experiments performed by Prof. Bigelow represent with wonderful similarity the coronal jets of the polar regions and the general coronal shape of the minimum period, but they do not account either for the equatorial extensions or for the forms proper to the period of maximum.

Electrical theory.—More recently several solar physicists, and especially M. Deslandres, have tried to find in electrical action a solution to most of the problems in connection not only with the corona, but also with the chromosphere, the prominences, and a large number of other solar phenomena, more or less intimately connected with them. They do not reject the intervention of other influences, such as heat, magnetism, and chemical combination; but, in their hypothesis, electricity remains the leading factor and, in many cases, the very generator of the other

[1] Bigelow: *Astronomy and Astrophysics*, 1893.

manifestations of energy. The following is a short *résumé* of their theory, as expounded by M. Deslandres.[1]

The hypothesis is not absolutely new. As far back as 1873, Tacchini and De la Rive favoured it so far as the prominences were concerned. More recently M. Fizeau adopted it; and even those who still consider other causes as the determining factors admit a marked manifestation of electrical influence. Sir William Huggins assimilates the coronal rays to the tails of comets, and these are generally attributed now to electrical action. As recently as 1893, a dielectric polarisation of external dust, and the production of sparks towards the interior in the coronal gases, were put forth as offering another explanation.

Amongst the various reasons which led M. Deslandres to the adoption of the electrical theory are the data furnished by spectroscopic investigations. Bright rays are constantly observed, not only in the chromosphere and the prominences, but also, though less intensely, in the corona itself, and amongst them are some which require electrical action for their appearance. Such are the characteristic rays of rarefied hydrogen. This gas, as has been said in speaking of prominences, heated at ever so high a temperature, has always refused to show them without the help of some electrical intervention; while they are easily obtained by means of the smallest Ruhmkorff's coil. It is therefore natural to consider their presence as the result of electrical action. By itself, this merely proves the co-existence of electrical manifestations, and does not establish the fact that electricity is the primordial cause of the concomitant phenomena; but as the light given by prominences, for instance, and certainly a part at least of that emitted by the corona, are chiefly due to incandescent hydrogen, it follows that at least their illuminating power has to a great extent an electrical origin. What has been said of hydrogen is highly probable of many other gases. All attempts to obtain their incandescence-spectrum, without electrical help, have given negative, or at most very doubtful results.

For the other coronal phenomena this theory also furnishes simple and apparently satisfactory explanations, a few of which will be given later on, and looks, at any rate, extremely plausible. A serious objection might be raised owing to the extreme state of rarefaction at which gases

[1] Deslandres: *Observations de l'Eclipse Totale du Soleil du* 16 *Avril* 1893.

must exist in that immense coronal atmosphere, in order that pressure in its lowest strata be not too considerable, as, at very low pressures, gases cease to be conductors. 'But,' says M. Deslandres, 'it would be enough to admit with Mr. (now Sir William) Huggins, that the gas forming the corona is not continuous, but is concentrated, in a kind of small atmosphere, round each of the solid cosmic particles,' a not unlikely supposition if these particles are really due to condensation through cooling.

The explanations proposed to account for the rays and streamers are not less simple and ingenious. It has already been said, in speaking of the chromosphere, that M. Deslandres considers it to be the result of electrical action, and attributes its luminosity to a phenomenon similar to the slow and continuous discharge taking place on our globe between high and low strata, and depending for its intensity on the difference of potential between them. This being admitted, a great step is taken towards the solution of the problem concerning the origin of the rays and streamers. We shall let M. Deslandres speak for himself:

'The question of the chromosphere once rendered more intelligible, a study of the corona becomes easier. The coronal spectrum proves that the small atmospheres surrounding the solid particles are electrically luminous. As the chromosphere is a vast electric spark, a plausible cause of the phenomenon is immediately suggested: the small atmospheres are rendered luminous by induction, as in the classical experiment with Geissler's tubes. On the other hand, the continuous spectrum may be attributed to the still relatively high temperature of the cosmic dust.

'But how are we to explain the peculiar forms of the rays and streamers? Here the difficulty is more serious, for we have no analogous phenomenon, our atmosphere having shown nothing as yet which could be compared to the coronal rays.

'Many hypotheses are possible, for it is difficult to check them. Mr. (now Sir William) Huggins supposes the electric charge of the particles to be of the same sign as that of the lower strata; hence repulsion. Again, equipotential layers being less distant above the faculæ, as was seen above, the charges and the repulsion could be stronger. In this hypothesis, account must be taken of the ultra-violet light strongly emitted by the disc, and which, according to recent researches, has the

property of discharging electrified bodies, and of giving to them a final electric charge, relatively weak, and varying with the pressure of the gas.

'I propose another hypothesis, better to my mind, and one which assimilates the coronal rays and streamers to the cathodic rays of rarefied gases. The higher chromospheric strata are highly electrified, and at very low pressure; if the charge be negative, the special conditions of Crookes' tubes are exactly reproduced. The bright areas of the chromosphere would emit cathodic jets, more active than those of the neighbouring regions, rectilineal and nearly normal, which would illuminate by phosphorescence the cosmic dust spread round the Sun. The forms, at first sight so strange, of the corona and of its rays, both straight and curved, are very easily explained in this way. The curvature of the rays would be due to the magnetic field and to mutual repulsion.

'This hypothesis furnishes also an easy explanation of the equal intensity of the coronal green ray, both in the rays and in the intervening spaces. In the case of the coronal dust, the small atmospheres, illuminated by induction, must have approximately a uniform brightness when the distance from the chromosphere is great; while the solid particles, themselves luminous by phosphorescence, have very unequal degrees of brightness, dependent on the direction of the cathodic jets.'

To conclude, let us add with M. Deslandres: 'Observations of the corona are not as yet sufficiently far advanced to allow of a serious discussion of these hypotheses.' And with this we shall rest satisfied for the present. Our idea was not to expound a theory, but merely to present, in a few pages, to that portion of the Indian public which may happen to be interested in these matters, a succinct compendium of the opinions expressed on the subject by the leading authorities in solar physics. Let us hope that the results obtained during the eclipse of 1898 will give us more abundant data, by means of which our knowledge of these interesting regions may acquire a greater degree of certitude.

CHAPTER IV.

THE SPECTROSCOPE AND ITS USE IN ECLIPSES.

THE spectroscope, in its different forms and applications, is the most efficient instrument modern science possesses for the unravelling of the many unsolved problems of solar physics. To follow the astronomer in his researches, and to understand their drift and the significance of the results obtained, some knowledge of the method pursued is absolutely necessary.

NATURE OF LIGHT.

The spectroscope is intended to separate from one another the several simple luminous elements forming a given pencil of light. Light is known to be the result of vibrations of different kinds to which the particles of a medium of imponderable matter, called ether, are subjected. It is useless to insist here on the nature of this medium, about which, moreover, little more is known than its existence and ubiquity.

Waves.—Since light results from the vibratory motion of these particles, it is but natural to expect that the laws it follows are very similar to those governing other vibrations: those of sound, for instance. In these last we distinguish two elements: the first is the rapidity with which the particle oscillates, or the rate of vibration, and this fixes the place in the musical scale or pitch of the sound; the second is the extent by which the particle is displaced, or the amplitude of its oscillation, and this determines the intensity or loudness.

There is something analogous to this in light phenomena, in which brightness and colour are respectively determined by the amplitude of the ethereal oscillations and their wave-length, the wave-length of a luminous vibration being a necessary consequence of its period. This will easily be understood. Let us suppose a rectilinear string of particles, capable of communicating to one another an up and down bobbing motion, and let

us start the first. However infinitesimal may be the time needed for the transmission of this motion, it will always be something, and the second particle will be somewhat behind the first in every phase of its oscillation, the third behind the second, and so forth; so that if at the moment the first particle has performed a few complete oscillations and has come back to its starting-point, we consider the relative position of the others, we shall find that, instead of forming as before a straight line, they describe an undulating curve above and below it, in the shape of a succession of S's, the length of each full S representing the space over which motion has been propagated during the time required for a complete oscillation of the first particle: this is called wave-length. It is true that this description refers only to rectilinear vibrations; this simplest case has been chosen for the sake of convenience, but analogous results, if more complex, are produced in the others.

Wave-lengths.—The length of the wave, other things being the same, is determined by the number of vibrations in unit of time: in other words, by the time it requires for a complete oscillation, independently of its amplitude, the wave being shorter in proportion to the rate of vibration. The amplitude, as has already been said, merely modifies the intensity, manifested, in the case of light, by its relative brightness.

In light, as in sound, vibrations of different periods may coexist, and produce effects more or less pleasant to the eye or to the ear. The resultant gives a compound colour, but the waves combining to produce it preserve their individuality, exactly as the vibrations of many piano wires sounding together in the most delightful harmony. In the case of pure white light, practically all the vibrations capable of impressing our organ of sight are coexistent.

Ethereal vibrations of every length are not all perceptible to our eye. Delicate as the organ may be, vibrations exist the wave-length of which is either too long or too short for it; in other words, their pitch is either too high or too low to excite synchronous vibrations in its optical fibres. Means, however, have been devised to record many of which the existence would otherwise escape observation. With waves of considerable length, of which the Hertzian waves form an interesting portion, we are not concerned now, for the means of study applied to them are of a

different order. We deal here only with those sufficiently short to give the perception of light, and those which, though invisible to our eye, may be recorded by ordinary photographic instruments.

Such is the minuteness of these waves that a special, almost infinitesimal, unit had to be devised for their measurement. It is called a tenth metre, and its length is the ten-millionth part of a millimetre. Now a millimetre is approximately $\frac{1}{25}$ of an inch, somewhat more exactly $\frac{10}{254}$; the tenth metre is therefore about $\frac{1}{254,000,000,000}$ of an inch. These are magnitudes which cease to represent anything to the imagination. Wave-lengths of rather less than 7,000 of such units begin to give, to a sensitive eye, the red perception, and as the length diminishes, we pass through the various tints of red and orange-red, and the successive colours of the spectrum, till lengths of about 4,000 land us deep into the violet. These are more or less the limits between which are grouped the luminous sensations of the sharpest organ, under the most favourable conditions. Photographic help is required for the detection of oscillations of still smaller wave-lengths.

Refraction.—Unless they encounter a disturbing cause, luminous vibrations are propagated through the ubiquitous ether in a direction normal to their plane, and one of these causes of disturbance is a change of density in the medium traversed. Then a deviation takes place, of such a nature that the angle formed either by the incident or the refracted ray and the normal to the surface of separation is smaller on the side of the denser medium. This deviation from their original direction is not the same for rays of different wave-lengths. When they fall obliquely with the same incidence on the dividing surface, the resulting change of angle—in other words, the amount of deviation or refraction—is greater as the wave-length is less. A little reflection will show that, with media of prismatic shape, the effect can be intensified, and it becomes possible so to increase the difference between the individual refractions that the rays, spreading fan-like at their exit, may be received separately in the eye or on a screen. The red rays are the least refracted, the violet ones the most.

SPECTROSCOPES.

The spectroscope is based on this phenomenon of refraction, and consists essentially of one or several prisms of a transparent material denser than air. A pencil of complex light, in its transit through them, is more or less refracted, and its several separated rays are received on a lens which produces, at the respective conjugate foci, as many images of the source of light as there are rays of different refrangibility. These images, of course, occupy the same relative position which the rays producing them would occupy, on account of their wave-lengths, in the spectrum of white light.

Grating spectroscopes are used for the same end as the prismatic ones; only, with the former, the phenomenon is one of diffraction and not of refraction, and the order of the spectral colours is inverted, the purple being the least diffracted. Gratings, as now constructed, consist of a reflecting surface, plane or concave, on which a number of parallel diamond-cuts have been ruled, with the result that very close and alternating bright and dull lines replace the former uniform smoothness. With dividing machines of his invention, Prof. Henry Rowland has succeeded in turning out gratings of 43,000 lines to the inch. The one used by our party had 14,438 to the inch, and a length of two inches. Instruments of this kind give several spectra more extensive, and from many points of view more satisfactory, than those of the prismatic apparatus.

An explanation of the way in which these diffraction spectra are produced would lead us too far and be too technical. It may besides be found in any treatise on Optics. Let us only add here that one of the advantages of the diffraction spectrum over the other is that in it the amount of deviation follows regularly the variations of wave-length, and that consequently it gives to each colour an extent proportional to its own relative importance in the spectrum. In the prismatic spectrum, on the contrary, the increase in the refraction of the several rays is greater than their corresponding diminution of wave-lengths, and the difference is greater as the wave-length becomes shorter. As a result the red and yellow, for instance, occupy less room in the spectrum, the violet more, than is respectively their due.

In the following explanations the refracting spectroscope will be considered; the same, with slight modifications, can be applied to the diffracting apparatus.

SPECTRUM.

When a beam of light falls on the spectroscope through a narrow slit, it may be considered as proceeding from it as from its source; and when, after refraction, the diverging rays of each colour are gathered together by a lens, they form as many different slit images as there are wave-lengths in the original light. If these wave-lengths exist in continuous series, there is a juxtaposition of images of different tints and colours; but let the rays of any given wave-length be missing, no light is refracted towards the position they ought to occupy in the spectrum, no corresponding image of the slit is formed there, and the vacant place is marked by a dark line. In the solar spectrum a multitude of these dark rays, of different breadth and intensity, are observed, and are known as Fraunhofer's lines.

Here we already have means of determining with exactitude the luminous wave-lengths contained in any given light; but we can go further. Not only do different substances emit lights differently constituted, but, though a body always emits the same light under the same conditions, this varies with circumstances, and especially with its physical state. Means are therefore indicated of distinguishing not only between various elements, but also of determining the conditions under which they are individually present in the luminous source.

Various forms of the spectrum.—A careful study and comparison of the spectra given by various lights has led to the following conclusions [1]:

1. Solid or liquid incandescent bodies, like the carbon particles in the electric arc, the lime of a Drummond's light, the molten steel of a Bessemer's converter, etc. always give a continuous spectrum.

2. The flame of gases, and of vapours burning under moderate pressure, or that of a body the combustion of which produces a gaseous compound, gives a discontinuous spectrum. Such is that given by the

[1] Cf. Secchi: *Le Soleil*, vol. i. ch. iii.

bluish part of a gas jet. Metallic vapours, rendered incandescent, give a spectrum of similar nature.

3. When the pressure, the temperature, or the degree of combustion of a gas or vapour is modified, spectra differing much from one another are obtained. Some, for instance, consisting of sharp, well-defined lines, under low pressure, have their lines diffused, and may even become continuous when the pressure is considerably increased.

4. Most incandescent metallic vapours give a spectrum made up of a few rays, separated by broad dark spaces. In the spectrum of some of them, however, as in that of iron, the bright rays are very numerous; these last spectra show a tendency to continuity under high pressure.

5. The positions of a large number of the dark lines observed in the solar spectrum exactly coincide with those of many of the bright lines proper to the spectrum given by metals and other substances, when in the state of incandescent vapours.

6. A vapour or a gas, at a temperature lower than that of the luminous source, absorbs precisely the same luminous rays it would itself emit were it incandescent. This phenomenon is called the reversing of the lines. It is produced, for instance, whenever the light given by an incandescent metallic vapour is examined through a layer of the same at a lower temperature. The greater the thickness of the intervening layer and the greater the difference of temperature, the more complete is the absorption.

Strange as this effect may appear, it is susceptible of a very simple explanation. Light has been said to be the result of ethereal vibrations; these, originating in the luminous source, are, unless interfered with, propagated in a direction normal to their plane. Here again we have a close analogy with what takes place in acoustic phenomena. Light obeys the same laws, which after all are nothing but those governing the transmission of energy. When a note is sounded near such an instrument as a harp or a piano, all the strings pitched to produce the same note or its harmonics are set vibrating, while all the others remain silent. This, of course, can only be produced at the expense of a certain amount of the energy by which the sound is propagated. The case is very similar with light vibrations. Those emitted by an incandescent vapour have definite wave-lengths, representing the periods of oscillation of its

particles under the given circumstances. Let a screen of similar but cooler vapour be interposed, that is to say, a screen composed of particles susceptible of the same vibrations, but in which these vibrations, if they exist, are of much smaller amplitude. Synchronous oscillations will be started or amplified, giving, with their harmonics, the fundamental luminous notes emitted; and this means absorption of energy at the expense of that producing the original light. The result is that the vibrations propagated beyond the vaporous medium are less ample than those emanating from the luminous source, and the light they give less intense. The absorption may be such that the portions of the spectrum illuminated by the rays so affected may even look dark, in contrast with those the illumination of which has not been modified. This remarkable optic property is invaluable to the student of solar physics, who finds in it a handy key to the cipher composing the despatches by means of which the Sun keeps us constantly informed of the current events of its surface and surroundings.

SOLAR SPECTRA.

Photospheric spectrum.—The photosphere gives a continuous spectrum crowded with thousands of lines, more or less dark and broad. A considerable number of these correspond exactly to the bright rays forming that of the incandescent vapours of a good many substances constituting our globe, while others have not as yet found their counterpart. These facts suggest two possible hypotheses.

1. Most of the substances known to us exist in the photosphere in a state of incandescence, and are mixed up with, or overlaid by, their own vapours at a relatively low temperature, causing the dark absorption lines.

2. The elements giving luminous radiations, the wave-lengths of which would place them in the position occupied by the dark lines, are wanting in the photosphere, or so poorly represented in it that their faint spectrum appears dark by contrast.

Chromospheric spectrum.—The photospheric spectrum alone does not offer a solution; but further study of our luminary leads us to discoveries which leave us no choice but to reject the last hypothesis, with regard to the majority of substances. When the slit of the spectroscope

is brought to bear on the narrow and vaporous chromospheric ring seen by projection round the solar disc, a widely different spectrum is produced. The rainbow coloured band totally fades off, except some weak remnants due to diffused photospheric light; at the same time a number of the hitherto dark lines become bright. A discontinuous spectrum, made up of bright lines, is that due to an incandescent vapour, and this leads to the inference that the substances which radiate corresponding wave-lengths are present in the chromosphere as incandescent vapours. The dark lines of the solar spectrum occupying the same position may, though, as will be shown, not necessarily, result from the absorption of light emitted by the same bodies at a still higher temperature. This point will be examined at the end of the chapter.

When, during a total eclipse, the spectroscope is applied to chromospheric researches, its slit may be dispensed with. The narrow visible chromospheric arc does duty for it, and the various rays of the spectrum obtained, which are nothing else but monochromatic images of the slit used, become crescent arcs of various length and breadth. These represent only the chromospheric layers in which the substances emitting rays of corresponding wave-lengths are contained.

Spectrum of prominences.—The eclipse of 1868 marks an epoch in the history of solar physics. An important item of the general programme of the observers was the study of prominences by the help of the spectroscope, which was still at that time a new method of investigation, so far as the chromosphere was concerned. The spectrum of these solar excrescences was then shown to consist of a number of disconnected bright lines, pointing to the presence of incandescent gases. Amongst these lines those of hydrogen, particularly F or $H\beta$, were predominant. Dr. Janssen, who was taking observations at Guntoor, was struck by the appearance and intensity of some of these lines, and asked himself whether it would not be possible to see them again in full daylight. Prevented by clouds from attempting the experiment immediately after the eclipse, he tried the following day, directing the slit of his instrument tangentially to a point on the Sun's border where a prominence had been seen the previous day. He was entirely successful. About the same time Sir Norman Lockyer obtained independently similar results. From that moment great strides have been taken in this direction, and it is now

established that, though hydrogen is always found in prominences and often forms the main part of them, many other vapours are also frequently present, amongst which those of helium, iron, and calcium are chiefly noticeable.

But the indications which the spectroscope give us do not end here. The refraction of a luminous ray depends on the wave-length of its vibrations. It is therefore evident that if the luminous particle moves in the direction of the line of sight with a velocity sufficient not to remain an infinitesimal quantity when compared to that of light transmission, the wave-length, and consequently the refrangibility of the ray, will be affected. If the translation takes place towards the observer, the wave-length is shortened, the refraction increased, and the refracted ray deviated towards the violet from its normal position; if it takes place away from him, the increased wave-length diminishes the refrangibility, and the ray is shifted towards the red. The extent of displacement on either side from the regular position of the ray in the spectrum testifies to the amount and nature of the modification undergone by the wave-length, and consequently to the rapidity and direction of the component of the motion along the line of sight. Other means allow of the measurement of the other components, and it becomes possible to determine with what velocity, and at what angle to the surface, the materials which form the prominences are ejected. I would call particular attention to the fact that it has been ascertained that the velocity of these bodies increases in many cases with their distance from the Sun, a fact which is in contradiction with the laws governing the velocity of ascent of ejected materials. We shall have further opportunities to refer to the significance of this apparently irregular phenomenon.

Coronal spectrum.—The usefulness of the spectroscope is not limited to photospheric and chromospheric observations. It is of much greater service in the study of the corona. We have seen that the regions occupied by this wonderful and puzzling solar envelope remain incapable of investigation except for a few moments during a total eclipse. What is its nature, and by what forces is it produced? On what materials do these forces act, and how? These and many others are the problems set us, and towards their solution much still remains to be done. We know as yet but little of the real nature of the corona, though much has

been learnt in this direction during the last twenty or thirty years. For instance, we know now that it has a material existence, and that it is not a mere optical illusion, nor a phenomenon of diffraction. We know also that it belongs to the Sun, and that it does not owe its origin to a possible lunar atmosphere. Spectrum analysis has shown that it possesses a certain number of the elements found in the other solar regions, though on this point our knowledge is still very limited. It is in these last investigations that the help of the spectroscope is particularly valuable.

The first spectral observations of the corona did not yield any special result. The method was new, and the existing instruments were not sufficiently adapted to these delicate researches, and as no coronal spectrum, differing from that of the Sun, could be detected, the corona was attributed to the reflection of diffused solar light. In 1869, however, Mr. Harkness observed, in the portions of the corona not corresponding to prominences, the characteristic coronal green ray so well known since as 1474 K. It is seen in no other solar region, and belongs to an unknown substance to which the name of coronium has been given. In the course of time other lines were detected, and in 1870 those of hydrogen, helium, and some other substances were found to be present, among them, in the lower strata, being iron, some of the lines of which were observed during the last eclipse by Prof. Pedler.

Beyond this discontinuous spectrum, the corona possesses another, faint and continuous, in which Dr. Janssen detected traces of absorption rays. Used without slit on the corona, the spectroscope gives a continuous spectrum, on which luminous circles of different intensities, instead of rays, are projected. The brightest is that corresponding to the coronal green ray, and this shows that the self-luminous portion of the corona emits a light consisting chiefly of this wave-length. It has been noticed that the brightest portion of the coronal rings do not habitually coincide with those of the solar rim on which prominences are abundant. This divergence seems to indicate a difference of origin with regard to place. Amongst the most distinct of the other circles are those corresponding to some hydrogen radiations, especially that representing the red line $H\alpha$. The presence of calcium, denoted by its H and K lines, is still very doubtful, as the observations taken before the last eclipse are contradictory. It is one of the problems to which it is hoped a solution may be

given this year; but it is too early as yet to say whether or not this expectation has been realised.

A fact established by several previous observations of the relative brightness of the coronal rays during different eclipses is that the luminous intensity of the light proper to the corona depends on the state of activity of the Sun itself. In 1871, 1882 and 1883, for instance, as well as in 1893, which were years of maximum, the green line was seen very bright, but it escaped observation in the minimum year 1878. Again, this year, which is close to the minimum of the eleven years' period, though the Sun manifests an apparent unusual activity, the green ray when observed was relatively faint; the other rings, however, seem to have been fairly bright, and brightest in places where prominences were absent. Let us add that the coronium light is seen all over the corona, even in the relatively dark spaces or rifts separating the bright rays, and that in them its intensity does not appear to diminish.

The continuous coronal spectrum may be due either to the juxtaposition of many indistinct rings or lines, or to the reflection of diffused solar light on coronal cosmic dust, or again to the incandescence of these particles. The well-marked polarisation of a considerable portion of the coronal light, noted by several observers, seems to point to reflection, while an electrical origin would account for the self-luminosity of the particles.

ABSORPTION IN THE SOLAR SPECTRUM.

A question has been left open: How are absorption rays produced in the solar spectrum?

As all the Fraunhofer's dark lines have not their counterpart in the bright lines of the chromospheric spectrum, opinions are greatly divided. Is absorption due exclusively to the chromosphere, in spite of its small depth, or to the presence of vapours in the photosphere itself? Is it not produced by other media, or perhaps by a combination of all these different causes? The weight of evidence, supported by the peculiarity of the spectra proper to various solar regions, seems to favour the latter view, and to attribute the phenomenon to a combined action of the photosphere, the chromosphere, the surrounding masses of cosmic materials, and our own atmosphere.

Atmospheric absorption.—The last of these causes can be dismissed with a few words, as scarcely anything can be learned of its action through eclipse observations. Dark lines, belonging to the spectra of atmospheric constituents, are weakened or intensified, according to the thickness of the atmospheric layer traversed. For instance, they are much more easily distinguished when the Sun is low on the horizon. This is especially the case with those due to water vapour. As a counter-experiment, Dr. Janssen, observing from the summit of Mont Blanc, remarked a great weakening, and in fact almost a complete disappearance, in the red of the group B, which belongs to the oxygen spectrum. About this atmospheric absorption there is no serious divergence of opinions.

Photospheric absorption.—The case is different with regard to the relative importance of photospheric or chromospheric absorption. There is not the slightest difficulty in admitting that the photosphere itself absorbs a considerable portion of the light it emits. Its fluidity does not necessarily mean a homogeneous state, purely liquid or gaseous. Indeed, careful study rather points to a mass of vapours, at high temperatures, in which innumerable clouds of liquid or solid incandescent particles remain suspended. The surrounding vapours would exert selective absorption on the waves of lengths proper to them.

This view is open to an apparently fatal objection. If absorption takes place in the photosphere, and is due to the selective action of its various vapours on the light emitted by the solid or liquid incandescent particles, the temperature of the latter must be higher than that of the absorbing medium. This can scarcely be the case if the vapours and the suspended dust belong to the same substances, as seems to be indicated by the absorption itself, for the temperature of vaporisation is higher than that of incandescence. It must, however, be borne in mind that the absorption of certain radiations by a vapour proves merely the presence in it of a body to the proper light of which these wave-lengths belong, and not necessarily its existence in the luminous source. When the light-emitting substance is an incandescent solid, or a liquid, its spectrum is always continuous, no matter what may be the nature of the body concerned, and the proper light belonging to it. The light emitted contains consequently rays of every wave-length. This, however, is not in contradiction with the

spectroscopic principle that each substance has its own proper light; but the constitution of solids and liquids offer to the regular development of the original oscillations obstacles which are not met with in gases, and, through the resistances encountered, new vibrations of every kind are generated. The modifications undergone by a gaseous spectrum of incandescence under pressure supports this theory; as the pressure increases the sharp bright lines are gradually transformed into luminous bands, showing the introduction of rays of different refrangibility, and consequently of different wave-length; and at times, under a very high pressure, which brings the vapour nearer its point of liquefaction, the bands can be made to unite so as to form a continuous spectrum. This being the case, it is clear that the presence of dark absorption lines in a spectrum does not prove in the solid or liquid source of light the existence of the substances to the spectra of which the lines belong, but merely their existence, at a lower temperature, in the absorbing vaporous medium. This consideration removes the difficulty of relative temperature. It is then enough to suppose, with Sir Robert Ball, that the solid and liquid particles of the photospheric clouds are chiefly made up of the less volatile elements, such as carbon and silicon, for instance, which could remain in an incandescent liquid or solid state, at temperatures sufficient to volatilise most of the others more or less completely. This theory once admitted, the photosphere can easily be considered as one of the great centres of absorption.

Reversing layer.—The chromosphere, however, cannot be regarded as inactive. There seems to be a growing tendency, supported by the latest observations, to attribute to its action a large part of the effect produced. This leads us to the controverted question of the reversing layer. Many solar physicists, among whom it is enough to mention Young, Lockyer, and Secchi, were inclined some years back to admit the existence of a chromospheric layer of special density, quite close to the photosphere, and giving a spectrum devoid of lines. The thickness attributed to it was scarcely 5″, and in their opinion the selective absorption of the substances forming this stratum was the main cause of many of Fraunhofer's dark lines. Further considerations, it is true, induced Sir Norman Lockyer to abandon this idea later on, but these views had still many adherents, and the question remained open, and one

of the problems to which attention was specially drawn during the last eclipses. Ocular affirmative testimonies were not wanting; and again, in 1896, Mr. Shackleton, in Novaya Zemlya, observed a flash spectrum which he attributed to it. Eye observations, however, of so delicate a phenomenon, with a duration of scarcely more than a second, remained unsatisfactory; personal errors and optical illusions were possible. What was wanted to settle the question was a photographic record. Atmospheric conditions prevented work of the kind in 1896; but greater success seems to have crowned the attempts made during the last eclipse. From what is known, up to this, of the results obtained at Jeur, Viziadrug, and some other stations, we learn that several good negatives of the flash spectrum, as it is often called, have been obtained. Further ocular observations of the phenomenon have also been taken during the eclipse. The existence, therefore, of the reversing layer seems to be a fact acquired to science.

Chromospheric absorption.—The other chromospheric layers are very likely responsible for further absorption, the amount of which is open to discussion. The whole question is one of density and temperature. These apparently vary much in chromospheric regions, and the spectra obtained seem to show that the lowest strata are not always the densest and the warmest. The number of bright lines forming the incandescent spectrum is also modified by the state of rarefaction of the vapours, and, as the researches of Sir William Huggins show, may even be reduced to a single ray when the rarefaction is very great. Again, other lines appear only at high temperatures, or, as in the case of hydrogen, are produced only by electrical action. Our negatives show that spectra of these different kinds may be got at different chromospheric altitudes, though no sign of them be found above or below. This seems to show that in some relatively high regions of the chromosphere the temperature may be higher than in those underlying them, and perhaps even higher than that of the photospheric vapours of the surface, a fact which agrees very well with M. Deslandres's electrical hypothesis.

It is worth noticing in connection with this, that on the chromospheric spectra taken at Dumraon during the last eclipse, the bright hydrogen line Hδ, corresponding to Fraunhofer's *h*, does not belong to the spectrum of the lowest regions, but is very bright and strongly marked

higher up. As this hydrogen line does not appear at temperatures lower than that of the electric spark, we have here an instance of upper strata being warmer than the lower ones, in which the presence of hydrogen is manifested by some others of its characteristic lines, such as Hβ and Hγ. The reduction of the calcium spectrum to H and K, and the characteristic blue line of this metal at some altitudes, while at others these are not visible but other lines are numerous, indicate also a variation of density and temperature in that vapour.

Enhanced lines, of which we shall have occasion to speak later on, are also a sign of heat variations. According to the accounts published up to this, they were not observed during the last eclipse. They are, however, often perceived during periods of greater solar activity. When they are present they point usually to a higher temperature in the vapours emitting them, and hence a diminution in their absorbing power. The Fraunhofer's dark lines, if they are mainly due to their absorbing action, ought consequently to become weaker, a fact which does not seem supported by actual observation. Perhaps, however, the accidental effect due to the enhancement, or accentuation, of some of these chromospheric bright lines is too faint to be easily perceived.

Coronal absorption.—Recent observations seem to point to further absorption of light in the cosmic atmosphere surrounding the Sun to unknown but certainly considerable distances. The presence in the coronal spectrum of faint dark lines, detected by Dr. Janssen, is a strong argument in favour of this hypothesis: but our knowledge of these regions is as yet too limited to allow of a serious discussion of the question. Some stress has been laid on the question of photospheric and chromospheric absorption, because the significance of the results obtained at Dumraon has a special bearing upon this. We shall have to come back on some of these points in the spectroscopic portion of the next chapter, in which these results are reviewed and discussed.

It would scarcely be useful, for the purpose of this work, to discuss at greater length these different points. The preceding notes will suffice for the end this and the preceding chapter have in view. They do not pretend to give a complete treatise on the solar constitution, and on the application of the spectroscope to its study, but are merely intended to help the lay reader to understand the problem to be solved, and to acquaint him with the steps taken during the last eclipse towards their solution.

CHAPTER V.

OUR RESULTS.

It is rather early yet to draw conclusions from the data obtained during the recent eclipse. Little as yet has been published about them by other observing parties, and months, perhaps years, of careful study will be required before definite conclusions are given to the public. Our own results, small as they are compared with those secured elsewhere with larger and more perfect instruments, present however a fairly large field for investigation. They give hints and indications that seemingly point to conclusions which we hope it will not be deemed presumptuous nor premature to mention here. These deductions are the outcome of a careful study of the negatives obtained at Dumraon by the St. Xavier's College Observatory party. They are given here as mere suggestions. Any one acquainted with solar work, and particularly that of a spectroscopic nature, will easily understand that observations of this kind require corroboration by comparison with others of the same kind, before the truth of any deduction they seem to lead to can be considered as definitely established.

PHOTOGRAPHY OF THE CORONA.

NO. 1 CAMERA.

No. 1 camera gave fourteen good pictures of the corona, besides two series of fifteen and eleven photographs respectively taken before and after totality. As the camera was specially intended to record the prominences, and as many as possible of the inner details of the corona, the streamers do not show to any great extent. That its object was fairly realised may be seen in Plates IX. and X., which reproduce the corona

with instantaneous and one second's exposures. A careful examination of the first will show numerous prominences studding the dark disc, while both pictures, but particularly the second, on which the coronal rays have a greater extension, indicate very clearly their curvature, together with their divergence from the poles and suction-like arching convergence towards the main streamers.

Four of the most characteristic negatives have been reproduced. A study of these will suffice to give an idea of the constitution of the inner corona. Before proceeding any further, however, the following general remark must be made about the different illustrations given. Many of the details found on the negatives are extremely faint, so faint that their detection requires the use of a lens. Such details are necessarily obliterated in the process of reproduction, however perfect the process may be, and however experienced the artists.

Plate V.—This curious picture of the eclipse has already been mentioned in a preceding chapter. A mere glance at it will suffice to detect the large triangular prominence to the left, and the triplet of bright ones diametrically opposite.[1] Another small prominence may also be noticed close to the large one but a little lower down. The middle of the three prominences to the right is somewhat higher than the other two, and has a curious form which unhappily could not be reproduced. It is in the shape of a T, or still better of the Greek letter τ, and consists of two parts. The first ascends from the chromosphere with a slight bend to the right; the other, which forms the top part of the τ, does not rest on the first, but remains suspended at a slight distance over it as a bright cloud. Between these three and close to them the magnifying glass shows several other small ones on the negative. It will also be easily perceived that nearly the whole of the upper half of the disc is bordered by a bright crescent very narrow elsewhere and with very slender cusps. This crescent is the photograph of the ruddy chromospheric arc still visible. On its outer border the two most remarkable of the many prominences studding it may already be noticed. One of them, not as yet very bright, stands out a little over 30° from the first one mentioned; the other, a larger one, is close to the vertex, a little to the left, just inside the bright

[1] It may not be inopportune to repeat here the caution already given in a preceding chapter. The figures represent the Sun as seen during totality; hence, looking at them we are looking southwards, and the left is the east, while the west is on the right side.

circle. It is represented in Plate VII. by the notch in the lunar disc seen some 60° higher up than the notch of the big prominence, almost at the centre of the circle, very slightly to the left of it, and became later on visible to the naked eye as a ruddy excrescence. Within this circle the whole border is crowded with metallic prominences. The intensity of the light does not as yet allow us to perceive them, but their presence is clearly attested by spectroscopic observations.

The picture given in Plate V. had an exposure of two seconds, during which first internal contact took place; hence the central part of the bright circle is partly formed by a photograph of a small speck, or specks of photosphere still remaining visible, combined with that of a portion of the chromosphere crowded with ejections of bright metallic vapours. The circles and the divergent rays themselves are probably due to a phenomenon of diffusion and diffraction. 'It is a well-known fact,' says Father Secchi,[1] 'that atmospheric air loaded with vapour produces diffusions and diffractions from which at times result irradiated circles acquiring an extraordinary brightness during eclipses.' On January 22 the sky was clear, but this of course is in no way inconsistent with a relatively high hygroscopic state of the atmosphere. On that day the mean humidity in Calcutta (Alipore) was 74. Behar is generally drier, and I could not get the corresponding information for Dumraon itself; but the state of things in Calcutta shows at any rate a tendency to no very great atmospheric dryness. Moreover, as the day was rather warm for the season, the absolute humidity is likely to have been above the normal.

Plate II.—The picture reproduced here was taken ten seconds after first internal contact, and had an instantaneous exposure. It still shows a chromospheric crescent, but narrower and less extensive. The same prominences are seen as on the preceding figure, but they are more distinct on account of the diminution of diffused light. Beyond these, many of the metallic prominences spoken of above may already be seen fringing the lunar disc, to the right of and at the vertex. A bright dot begins also to appear near the lowest point of the rim.

The first indication of a curious instance of rapid birth, growth, and complete disappearance of a prominence is seen on this photograph. All was over in some eighty seconds. This phenomenon presents a special

[1] Secchi: *Le Soleil*, vol. i. p. 360.

interest. Owing to its short duration, it could not be observed at other stations than Dumraon and Buxar, as at the time they had their period of totality, it had not begun or was already over. On Plate XIII. fig. 5, is reproduced, considerably enlarged, the group of prominences seen on the western limb of the Sun. To their left, and at a distance nearly the same as that separating the first from the third, may be seen close to the lunar disc a small portion of the coronal inner ring slightly brighter than the rest. On plates exposed later on, three small prominences appear at the base of the cloud. At first they are rather indistinct, but increase gradually in size and brightness for nearly sixty seconds, and show a tendency to union. Then in three seconds time, from the sixty-eighth to the seventy-first second of totality, a sudden outburst takes place, and the maximum shown on Plate XIII. fig. 6, is attained. A rapid fall follows: some traces of this curious prominence can still be seen on the negative taken at the eighty-seventh second, but nothing on the plate exposed at the ninety-sixth, only twenty-five seconds after the maximum was reached.

Something of the radiating coronal structure can already be perceived here very faintly at the solar poles. These are in the portions of the corona almost at right angles to the diameter joining the large prominence to the three opposite ones, where it appears less broad. The position occupied by the five main streamers is also indicated by coronal extensions. Other details might be observed, but they are repeated with greater clearness and intensity on the other photographs.

Plate VIII.—This negative had an exposure of two seconds, and was taken twenty-eight seconds after the beginning of totality. This length of exposure was already too much for the prominences, which almost completely disappear in the very actinic light of the innermost bright ring. The situation of the chief amongst them is indicated by notches in the lunar disc. As has been said elsewhere, these notches are due to diffraction and continuation of chemical action. The most remarkable character of this picture is the fair amount of clearness with which the radiating coronal structure is set forth, especially near the south pole and at the western and south-western streamers. Another interesting coronal feature evidenced by this photograph is the persistent way in which the rays are arched and bent towards the streamers on both sides of them, while towards the middle they are almost straight and in the direction in which

the streamers are produced. The rifts are here more accentuated, especially near the south pole, though none of them reach the lunar disc. To the left of the base of the big streamer, the one at the south-west, as well as in the southernmost portion of the one at the west, indentations begin to be seen marking the separation of two minor streamers existing there. These last, and still a third one, are better seen on other negatives.

Plate VII. The exposure of half a second given to this plate, about mid-eclipse, forty-two seconds after first internal contact, allows of a better reproduction of inner coronal details; though, except for the notches they produce on the lunar disc, the prominences cannot be distinguished. The radiating structure remarked in the last picture is seen to persevere in more interior portions of the corona. Indeed, the arching of the rays towards the streamers is more characterised, especially in the case of those to the north-east and to the west. The same can be said of these divergences from the poles, as if centres of repulsion existed at these points. Rifts can also be seen, especially one more strongly marked near the root of the large streamer, and several near the south pole.

Photographs before and after totality.—Out of the twenty-six photographs taken before and after totality, all but two are satisfactory, and show clearly the fine groups of spots visible at that time on the surface of the Sun, and the gradual encroachment on them of the lunar disc. The unsuccessful negatives had accidentally too long an exposure. A plate exposed a few seconds before totality shows slight signs of a beginning of Baily's beads, but much too faint to bear reproduction.

NO. 2 CAMERA.

An untoward accident, just at the critical time, and detected only later on, impaired the usefulness of this instrument.

NO. 3 CAMERA.

Twenty negatives were obtained with this apparatus, fourteen during totality, and six within the following minute. This instrument was intended to record further extensions of the corona and streamers than

those obtained by the first, and inner details had to be sacrificed in consequence. On the other hand, the streamers were photographed to a good length, attaining as much as two lunar diameters on some negatives. These photographs seem to point to the conclusion that the actinic power of the streamers diminishes more rapidly than that of the corona proper as distance from the Sun increases. On the negatives with two seconds exposure, extensions of the corona are shown which, to the eye, looked certainly less bright than portions of the streamers which have left no trace. We reproduce six of the pictures taken with this instrument.

Plate VI.—This photograph had an instantaneous exposure a fraction of a second after first internal contact. On it the curious phenomenon observed on Plate V. is repeated, but with greater extension. This may easily be accounted for. This photograph was taken nearly one second after the other, when the most luminous portions of the Sun's border, the primary cause of the phenomenon of diffraction, had sensibly diminished in extent. The bright circle has a longer inner diameter, and is much broader and brighter, but the inner diverging rays are burnt into a confused luminous disc. The inner coronal details disappear also, but the streamers already begin to be clearly indicated, especially the long one at the south-west.

Plate IX.—The picture reproduced here had an exposure of two seconds forty-eight seconds after the beginning of totality, but was taken on an ordinary plate, and not on a drop shutter special. Compared to that of the first, the corona has considerably increased in breadth, while the streamers have received but little extension; it may even be remarked that the western one, which was less bright, scarcely extends at all beyond the corona proper. This seems to confirm what was said above about the difference in actinic power between the two. Some indications of radiated structure may be noticed here on the extreme border of the corona.

Plate X.—This photograph, obtained at the sixtieth second of totality under conditions exactly the reverse of those of the preceding one, leads to the same conclusion. It was taken on a drop shutter special with half a second's exposure; the other, on a slow plate with an exposure of two seconds. Again the corona manifests its superior actinic power, and is almost as developed as the streamers themselves.

Plate I.—The streamers are seen to greater advantage in this picture,

taken at the seventy-third second, with two seconds exposure. The separation of the fifth streamer from the larger one at the west is marked. This fifth streamer was much shorter and weaker than the others at Dumraon, and very likely at Buxar too, and this may explain why several observers only noticed four. On account of the exposure, the corona proper is much larger than was observed with the naked eye.

Plate XI.—Fig. 1 of this plate was obtained ten seconds after last internal contact, with one second's exposure. The picture is particularly interesting as, in spite of the reappearance of a thin solar arc, the whole of the corona is still perfectly visible with very distinct and fairly extended streamers. A similar result was obtained at Ghoglee by Dr. Copeland. The great extent of the corona, notwithstanding the already strong diffused light of the Sun, shows once more its considerable actinic power.

In fig. 2 is reproduced a photograph taken thirteen seconds after the end of totality with an exposure of two seconds. The image of the thin photospheric arc visible at the time is of course solarised, and considerably thickened in its brightest part, through effects of diffraction and continued chemical action. It is seen broken up into a number of Baily's beads more or less distinctly separated. Two other interesting facts recorded are the visibility of traces of the bright circle of diffraction noticed at the first internal contact, and of the entire lunar disc projected on a faint background of coronal light.

This last phenomenon was also reproduced, but with much greater clearness and intensity, on three negatives taken with No. 1 camera ten, twenty-six, and thirty seconds after last internal contact. Even the largest prominences are clearly visible on the plates, together with the brightest portion of the corona to an extent of over half a radius.

PHOTOGRAPHY OF THE SPECTRUM.

PRISMATIC CAMERA.

Some good chromospheric spectra, with faint traces of the spectrum of the brightest coronal inner ring, were obtained with this instrument. The shortness of exposure, necessitated by the absence of clock-work motion,

and the small amount of light received, resulting from the small aperture of the apparatus, prevented further results being obtained. Nevertheless, the chromospheric spectra are very satisfactory and interesting. Three of them have been chosen for reproduction. On the original negatives they extend from near *b* to between 3,900 and 3,800, beyond K; but these two extreme portions, together with many faint details and arcs, could not be reproduced. As they stand, the spectra may be seen to consist of six large and bright arcs, between which are thickly strewn a number of shorter ones of various sizes and brightness. At a short distance from the more slender horn of the longer arcs are seen triangular white dots, as well as smaller ones in the broadest part of the others. Negatives taken at a later period, when the long arcs were reduced to mere threads, show that these smaller dots were also present in them.

Many are the instructive data hidden under these apparently insignificant hieroglyphs.

Plate XII. Fig. 1.—The first negative received an exposure as instantaneous as can be given by hand, and was taken nearly one second before totality. It shows four superposed spectra: 1. An almost linear, bright and continuous spectrum; 2. Another continuous spectrum, but fainter and broader especially at the extremities, and seemingly made up of juxtaposed linear spectra; 3. A discontinuous spectrum, made up of arcs of different lengths and brightness; 4. A similar spectrum, in which the arcs are replaced by dots.

Fig. 2.—On the second negative, taken two seconds after first internal contact, with an exposure of half a second, the first spectrum has disappeared, together with a good many of the shortest and faintest arcs; but, just on that account, the remaining ones and the accompanying dots stand out more clearly.

Fig. 3.—This figure represents what is left of the second continuous spectrum forty seconds after first contact, when most of the prominences dotting the arcs had been eclipsed.

We shall examine in detail these various spectra.

1. First Continuous Spectrum.

The first, or bright, linear and continuous spectrum needs little comment. It is due to the speck of photosphere still remaining visible,

2. Second Continuous Spectrum.

The second spectrum, also continuous, but fainter and broader, is more instructive. It consists of a series of brighter longitudinal bands in juxtaposition, sometimes united by traces of weaker continuous light. A look at the negatives shows clearly that, whatever may be the origin of this spectrum, it is extra-chromospheric. The prominence rays are projected on it, and it remains visible when the chromosphere has completely disappeared. It probably represents the spectrum, or rather the spectra, of more luminous portions of the coronal ring adjacent to the chromosphere. The connection between the bands and the prominences is evident, as the position of each of the first answers exactly to that of one of the second. They cannot, however, be the spectra of solid and incandescent photospheric particles ejected together with the gaseous masses, for they persist after the prominences have been hidden (see fig. 3). They must therefore belong to special regions of the coronal inner ring, sufficiently bright to be reproduced on our negatives, which record no other traces of the coronal spectrum. The hypothesis of any play of light in the instrument cannot explain them away, as part of the same phenomenon was noticed by ocular observation. The Rev. F. X. Haan, S.J., a member of Prof. Naegamvala's party, observing at Jeur through a direct vision spectroscope of five prisms adapted to an equatorial, saw an unusual continuous spectrum which at first sight seemed connected with one of the brightest prominences. This is the only band he had time to notice, but the fact is sufficient to establish the real existence of these linear continuous spectra.

The electrical theory referred to in the preceding chapters affords a simple explanation of these curious effects. If, as this theory maintains, the corona is mainly electrically luminous, and that by induction, and if, at the same time, prominences are electrical phenomena of special intensity, it is but natural to admit that the electrical illumination by induction of the coronal regions, surrounding the highly electrified masses projected through them, is simultaneously enhanced, and an instrument, not sensitive enough to reproduce the ordinary coronal spectrum, may still be sufficiently active to record that of these brighter regions.

A further study of the various spectra secured at Dumraon during the

eclipse, and of the modifications these luminous bands undergo in them, seems to confirm this opinion. The band answering to the large prominence at the south-east, which remained visible during the whole of totality, was practically unchanged all through; the others, corresponding to the prominences seen in the neighbourhood of the point of first internal contact, persisted after the disappearance of the prominences, but they generally grew weaker as the lunar disc moved in their direction. Some, answering to the smallest projections, vanished after a time, but those corresponding to the largest impressed the plates, though less and less strongly, till the end of totality. A little after the middle, another band appeared towards the point where the last internal contact was to take place, and its appearance was soon followed by that of another large prominence, occupying the same position.

3. First Discontinuous Spectrum.

Cutting through these two spectra are seen numerous bright arcs, which represent the discontinuous spectra given by incandescent chromospheric vapours. Of the six longest, the first and the second, as well as the fifth, belong to calcium, and correspond to the Fraunhofer's lines K, H, and to its characteristic blue ray; the first two are in the violet. The third, fourth and sixth are hydrogen arcs, and represent respectively $H\delta$ or h, $H\gamma$ and $H\beta$. We shall first examine the deductions suggested by the hydrogen arcs.

The $H\delta$ ray.—The three hydrogen arcs present interesting peculiarities. The third arc counting from the left is the h line or $H\delta$, and is much more slender than the other two. It is sharply defined at its convex boundary, and is nebulous and undulated inside (Plate XIII. fig. 3). Experiments have established that $H\delta$ is not visible as a bright line in the hydrogen spectrum, unless electric power is used to obtain it. Its presence, as a bright line, in the chromospheric spectrum is therefore a sign of a temperature at least as high as that of the electric spark. It may also be noticed that the arc is long, but relatively slender. The arcs produced in such a spectrum are images of a crescent formed by the intersection of a ring—the chromospheric ring, or concentric rings—by a circle of somewhat longer apparent diameter—the lunar disc. As a con-

sequence, the resulting crescent is made up of concentric arcs of diminishing length, the outer and longer ones being parts of the outer chromospheric rings, while the inner rings are represented by the inner and shorter arcs. Bearing these facts in mind, let us once more examine the $H\delta$ arc, such as it presents itself in the chromospheric spectrum.

It is long; in fact, it occupies nearly the whole length of the visible portion of the chromosphere, but it has not the kind of outer bulging seen in the fourth and in the sixth arcs. On the contrary, it is slightly flattened at the corresponding spot. Its outer curve is sharp, but the inner one is cloudy and wavy, and is not contiguous to the lunar disc, a fact made plain by the curvature and thinness of the arc. It has been said before that the presence of $H\delta$, as a bright line or arc, proves the existence of hydrogen at a high temperature, but the position and shape of the arc given on the photograph show also that the degree of temperature required, so far as it may be due to electrical action, was attained only in high chromospheric regions, and that at lower altitudes, hydrogen, which attests its presence by the other rays, must have been cooler. The wavy and almost lumpy character of the inner portion of the arc is due, as will be seen later on, to the superposed spectra of prominences.

The $H\gamma$ ray.—The fourth arc answers to the hydrogen ray $H\gamma$ in the indigo-blue (Plate XIII. fig. 4). In character, it differs much from the $H\delta$ arc. It is much broader and brighter, and its inner curvature, the same as that of the arcs belonging to the lowest strata, shows that it reaches the lunar disc. Its outer curve, however, is a little vaporous towards the middle, and bulges out somewhat. Moreover, a close scrutiny will detect a faint misty extension in the same direction, for a short distance. Here, then, we have proofs of the existence of hydrogen through the whole of the visible portion of the chromosphere, though its temperature in the lower regions is shown, by the absence of the $H\delta$ arc, to be lower than in higher strata. The bulging in the middle of the outer curve indicates chromospheric upheaval at that point, and the misty mass protruding from it testifies to a disturbance in the chromospheric surface, and to the ejection into space of rarefied and cooler hydrogen. This hydrogen very likely comes from the lower and cooler regions, as its spectrum gives no sign of the $H\delta$ line. This is confirmed by the depression noticed in the $H\delta$

arc at the places of apparent eruption, a fact pointing to a fall of temperature in those regions. The existence of several very bright metallic prominences, found on the corresponding limb of the Sun, and reproduced more or less distinctly in most of the metallic arcs of the spectrum, furnishes an obvious explanation of the phenomenon.

The Hβ ray.—This arc is unhappily in a part of our spectrum less perfectly focused, but as much as can be distinctly seen presents characters similar to those of Hγ. This was to be expected, as Hβ is the most permanent of the hydrogen lines, and is the only one left when the spectrum is reduced to its simplest expression. It is, therefore, sure to be present whenever hydrogen gives a spectrum at all.

The K ray.—The first long arc of the spectrum reproduced is the calcium K line. It is very similar in shape to the hydrogen Hδ arc: a long slender arc, belonging evidently to the spectrum of the upper chromosphere (Plate XIII. fig. 1). Its more strongly accentuated inner curve and greater thinness show, moreover, that it does not extend to such low strata as Hδ, and that the conditions under which the K line becomes bright in the calcium spectrum existed only in the upper regions at the time of the eclipse. It is to be regretted that, owing to the action of heat, a small corner of the dark lining of the slide-holder got loose, and cut off parts of K and H.

The H ray.—This calcium radiation gives the second long arc (Plate XIII. fig. 1). It appears as if made up of two portions: the first almost identical in shape to K; the second corresponding in position to the bulging observed in the Hγ and Hβ hydrogen arcs. To the long thin arc the same remarks may be applied as to K; the other portion seems quite a different arc, corresponding to another wave-length. In this case the shortness of the arc relegates the substance to which it belongs to the lowest chromospheric layers. There is, however, no line in such close proximity to H which it could represent, except some very slender and faint ones, left undetermined in Ångström's spectrum, and one of the same kind, but on the other side, belonging to iron. It is, of course, possible that one of these undetermined lines may belong to the calcium spectrum, a fact I have no means of verifying; and in that case the vapours producing it would pertain to the same low levels as those of the other calcium arcs. Unhappily, as was said above, a portion of H and K

was accidentally cut off, and this renders a conclusion more difficult. The scarcity of calcium rays in the spectra of the prominences does not constitute an objection; it simply testifies to the rarefied state of these metallic vapours.

The calcium blue ray.—The fifth long arc corresponds to the group near 4461 of Ångström's spectrum, and seems due to calcium (Plate XIII. fig. 2). It is very likely the characteristic blue line of its spectrum. Its peculiarities are the same as those of the Hδ arc, but are more strongly marked. The arcs H and K, and this one, are the only ones testifying to the presence of calcium in the upper regions, where consequently its vapour must have had but little density. Many other short arcs point to the existence of this metal at low levels, but the length, curvature and thinness of the fifth arc, and consequently the absence of the blue line from the spectrum of the lower strata, is a corroboration of the proof already afforded by the Hδ arc of different conditions of temperature at different chromospheric altitudes. The arc has no bulging out except two very slight projections on both sides of the middle portion, each of which corresponds to a metallic prominence, a proof that calcium, under conditions rendering the blue ray visible, is wanting in the greatest part of the chromospheric extension seen in the arcs Hβ and Hγ. Its inner curve, even more splotchy than that of Hδ, denotes calcium in the prominences already mentioned. These are the bright metallic prominences fringing the Sun's limb near the point of first internal contact. Their great brightness was likely due in part to calcium. The overlapping of an iron arc, in which the prominences are strongly marked, may also contribute to the splotchy appearance of the whole.

The shorter arcs.—Many other arcs are also visible. Over 250 can easily be counted on the negatives, and several appear as the result of the overlapping of two or three others. These arcs, with some exceptions, are considerably less bright than the long ones, and are much shorter, though their respective lengths slightly vary. They belong, therefore, to the lowest layers. Many of them are produced by calcium, iron and titanium, while others seem to coincide with lines of manganese and of a few other substances. The calcium arcs are generally the brightest, and are often also a little longer, showing that calcium vapour, giving rays sufficiently bright to be recorded by our plates, existed

higher up than most of the other metals in the low chromospheric strata. It does not, however, follow from this that these metallic vapours were altogether wanting at higher altitudes. Calcium has already been shown to have been probably present even in the chromospheric bulging, but under other spectroscopic conditions than those lower down, while eye observations and more sensitive photographic instruments have located iron, for instance, in the whole chromospheric extent, and during the last eclipse Prof. Pedler detected some iron lines even in the lower coronal regions.

A bright arc near *h*, and on the H side of it, deserves special mention. It answers plainly to one of three nebulous lines, very close to one another, and extending from 4076 to 4078·5 in Cornu's extension of Ångström's spectrum. I am not in a position to identify this arc with any certainty as belonging to the spectrum of any known substance, but it seems to belong to calcium.

Amongst the numerous arcs identified on our negatives are the following, which stand amongst the brightest: 4030, 4186·2, 4387, 4404·2 of iron, and its characteristic arc lines between 4045 and 4071; 4215·5, 4226·4 of calcium, and 4249·5 common to these two metals. The group G is also heavily represented. A certain number of the arcs cannot so far be determined; some of them are still doubtful, and in the case of others, only more or less probable guesses can be made, as they necessarily escape the imperfect means of investigation at our disposal.

4. Second Discontinuous Spectrum.

A number of bright prominences were observed on the solar rim during totality. Several of those visible at the beginning of it have left their spectrum on the negatives we reproduce.

The large prominence.—The triangular bright spots met with near the sharpest extremity of every one of the longest arcs represent the main spectroscopic lines of the large prominence seen by most observers on the west limb of the Sun, and visible as long as the eclipse lasted. Many noticed that it emitted a more or less white light, while others remarked that it had a white base capped with red. This is borne out by its spectrum. The hydrogen of red prominences is strongly shown by well-

marked dots near every one of the hydrogen lines; the one near $H\delta$, however, is weaker, and indicates that the temperature of the gas was somewhat inferior to that it had acquired in the upper regions of the chromosphere. The white and dazzling appearance of the light is explained by the presence of calcium, demonstrated by the strong dots accompanying the three long calcium arcs. No spot in the corresponding position is found in connection with any of the other arcs, and unless, as is not unlikely, this is partly due to want of light and of sufficient exposure, it indicates a great state of rarefaction of the calcium vapour, and the absence of that of the other metals.

Prominences near the point of contact.—The case is different with the string of prominences fringing the border of the Sun near the point of first internal contact. Several of them, though not very high, were of fair size and very bright, one of them being particularly noticeable. Their spectrum shows, beyond the lines of hydrogen and calcium, very numerous metallic lines of different kinds. This is what is meant by the bright dots visible in most of the metallic arcs forming the chromospheric spectrum. The short arcs of calcium, however, show but very faint traces of prominences, if any at all—another proof of the rarefaction of this metallic vapour. In these prominences, therefore, calcium, iron, titanium and other metals were present, and as most of these vapours are shown to belong to the inferior strata, the height attained by some of these metallic prominences testifies to the existence of a violent disturbance affecting the chromosphere to its lowest depth. These facts furnish an explanation of the very noticeable chromospheric bulging recorded by the arcs $H\beta$ and $H\gamma$. Later on, during the second half of the eclipse, another prominence, at the south-west, gave a spectrum very similar to that of the first. We regret to say that the negatives taken towards the end of totality are not sufficiently clear to be of much use in investigations.

GRATING CAMERA.

The results given by the grating camera were rather disappointing, but this was the consequence of the short exposures which the want of clock-work motion necessitated. The red end of the spectrum, nearly up to $H\beta$, refused altogether to impress the plates, and the invisible ultra-

violet portion behaved little better. However, some interesting though faint photographs were obtained of the part extending from about Hβ to a little beyond K, the segment about H and K being the best. These negatives are unhappily too weak for reproduction. The best of them was taken after mid-eclipse, seventy-three seconds after its beginning. The spectrum consists of interrupted rings, constituted for the greater part by the juxtaposed images of bright prominences. The light of the intervening bright inner ring of the corona did not prove actinic enough to impress the plates to any very perceptible extent under these conditions. The rings are: 1. H and K of calcium; 2. Hβ, Hγ, and Hδ of hydrogen, these latter, especially the last, very weak; 3. Some faint traces of iron and calcium rings, on both sides of H and K. Among these are the iron groups, about 3895 and 3840, in the ultra-violet.

The rings themselves are interrupted at any spot where a prominence is not present, and their luminous portions are of various brightness. The large prominence of the eastern limb, and the three bright ones almost diametrically opposite, are strongly represented, as well as the many smaller ones accompanying these last, and also a good part of the fine string which appeared later on the south-west border. Tangential to all the rings can be seen some faint linear indications of coronal spectrum. The main interest of these photographs consists in the confirmation they afford of the indications given by the other spectra about the large prominence. They also show the presence of iron and calcium in the string of prominences diametrically opposite, and in those which appeared on the south-west border during the second half of totality.

TIME REGISTERING APPARATUS.

The following is a general table of the photographs secured by the various instruments during and immediately after totality, with their length of exposure and their distance from the time of first internal contact, expressed in seconds. The plates used were drop shutter specials, unless otherwise indicated.

No. 1 Camera			No. 3 Camera			Prismatic Camera			Grating Camera		
Phot.	Expos.	Time	Phot.	Expos.	Time	Phot.	Expos.	Time	Phot.	Expos.	Time
1	2	0	1	Inst.	1	1	Inst.	−1	1	2	0
2 [1]	Inst.	10	2	½	4	2	½	+2	2	2	5
3 [1]	½	13	3 [2]	1	16	3	1	5	3	2	13
4	1	24	4 [2]	2	19	4	2	8	4	2	17
5	2	28	5 [1]	Inst.	27	5	Inst.	12	5	2	37
6	Inst.	39	6 [1]	½	30	6	½	15	6	2	41
7	½	42	7	1	45	7	1	28	7	2	52
8	1	54	8	2	48	8	2	31	8	2	66
9	2	58	9	Inst.	57	9	Inst.	35	9	5	78
10	Inst.	68	10	½	60	10	½	37	10	2	80
11	½	71	11	1	70	11	1	40	11	2	83
12	1	83	12	2	78	12	2	43	12	2	87
13	2	87	13	Inst.	82	13	Inst.	54	13	2	96
14	Inst.	96	14	½	85	14	½	57	14 [3]	2	101
15 [3]	½	108	15 [3]	1	108	15	1	60	15	2	108
16	1	117	16	2	111	16	2	64	16	2	113
17	2	121	17	Inst.	128	17	Inst.	67			
			18		131	18	½	70			
			19	1	143	19	1	85			
			20	2	146	20	2	88			
						21	Inst.	93			
						22 [3]	½	108			
						23	1	111			
						24	2	117			

SOLAR ACTIVITY, AS SHOWN BY THE SPECTRUM.

Before proceeding any further with the discussion of the materials gathered at Dumraon during the eclipse, it may be useful to stop awhile, and give some attention to a solar problem on the solution of which the data furnished by the spectrum may help to throw some light.

The chromospheric spectra taken during totality have been shown to contain numerous metallic arcs, those of iron being particularly abundant, though greatly inferior in number to the iron dark lines of Fraunhofer's spectrum. From the scanty data obtained from other stations, the results attained, with reference to this point, show similar characters. From a spectrum produced without a slit it is scarcely possible to judge of the existence or non-existence of enhanced lines; but if the few observations published to this day are exact, these lines seem to have been absent, especially from the iron spectrum. From this circumstance the scientific correspondent of a Bombay newspaper rather hastily infers an increase of solar temperature at the present time.

[1] Instantaneous plate. [2] Ordinary plate.

[3] This plate and those following were exposed after totality.

'During the eclipses of 1893 and 1896,' he writes, 'amongst the bright lines recorded, enhanced lines formed an important feature, showing a moderate temperature; while during the recent eclipse the absence of these lines clearly indicated unusual activity in the Sun—unusual, that is to say, for the minimum epoch of the Sun spots period. Inferentially, therefore, the temperature of the Sun appears to be very high just now.'

Variations in the iron spectrum at high temperatures.—Such, however, does not seem to be the case. Let us examine the results obtained with reference to these different points, and compare them with what is known, from former researches, of the variations of spectra, and especially of the iron spectrum, due to changes of temperature. Of course the temperatures at which the experiments are performed must be the highest attainable, in order to reproduce, as far as possible, the conditions obtaining in the solar chromosphere. Hence the spectra studied are those given, (*a*) by the electric arc, (*b*) by the electric spark, (*c*) by stars of different temperatures. The temperature of stars is ascertained by the relative length of their spectrum in the ultra-violet, the hottest star having the greatest elongation in that direction. The iron spectrum has been particularly studied from this point of view, and is taken as a kind of standard, both because it is a frequent constituent of celestial bodies, and because variations among its many lines are likely to be more numerous and more easily detected.

The arc spectrum of this metal shows all the Fraunhofer's iron rays as bright lines, but generally shorter. At the higher temperature of the spark, a large proportion of them disappear, but others are notably elongated, and some get brighter; these last are the enhanced lines. The presence of these lines, however, does not, as will be seen, necessarily denote a temperature higher than that indicated by their absence; it shows that the temperature of the metallic vapours is superior to that simply producing a spectrum rich in other lines, but in which they are wanting.

Iron lines in stellar spectra.—Stellar spectra throw new light on the subject. It has been said that the temperature of stars is indicated by the ultra-violet extension of their spectrum; it is, therefore, in that region we have to look for the most characteristic spectral modifications due to heat. A certain number of the iron lines noticed in the purple arc

characteristic of its arc spectrum, that is to say, they are not found, for instance, in its spark spectrum. Such is the triplet between 4045 and 4071 of Ångström; others, such as the quartet about 4482, are lines susceptible of enhancement. Now, in the spectrum of relatively cool stars, such as α Orionis, these enhanced lines are absent while the arc lines can be seen, but all the shorter as the star considered is less cool. As the temperature increases, enhanced lines begin to appear, very long at first, but diminishing in size and in number as the heat becomes more intense. This is the case with Rigel, in the spectrum of which the quartet is reduced to three short lines. At that stage the arc lines have disappeared altogether. In the hottest stars, like Bellatrix, even the enhanced lines vanish, and no trace of the iron spectrum is left.

The natural conclusion seems to be that, of three iron spectra containing—1, a number of arc lines, but no enhanced ones; 2, both arc and enhanced lines; 3, no arc lines, but some enhanced ones, the first indicates the lowest, the last the highest degree of heat.

Eclipse observations.—As was said above, it seems that enhanced lines, and especially those of iron, were absent from the spectra observed or photographed during the recent eclipse, while the iron arc lines were very numerous. Though materials for the verification of the first point are not within our reach, as we did not make use of a slit, the second is fully corroborated by the indications of our negatives. Not only that, but the very triplet of characteristic arc lines between 4045 and 4071 is clearly represented. On the other hand, the quartet about 4482, composed of lines susceptible of enhancement, is scarcely perceptible, and its very identification is doubtful.

In 1893 and 1896, a number of iron enhanced lines were observed; a fact which seems to indicate that the chromospheric temperature is now lower, not higher, than during the preceding years. Add to this that during the eclipse of 1882, a year of quite extraordinary solar activity, the number of enhanced lines observed was considerable. The only way therefore of reconciling the absence of such lines in the spectra of 1898 with a temperature higher than that of 1893 and 1896 would be the untenable hypothesis that, though solar activity is for the present greatly inferior to that of 1882, nevertheless the temperature of the chromosphere is considerably greater.

Objection from the present unusual number of Sun spots.—A serious difficulty presents itself at this point. It has already been said that the present year ought regularly to be nearing the minimum, and, as such, to be characterised by a minimum in the number and extent of the Sun spots. Such, however, is not the case; and not only have an unusually large number of spots been observed, but amongst them were several of fair size. This points to rather great solar activity, and consequently to a relatively high temperature, and seems in contradiction with the indications given by the spectrum.

Without presuming to put forward anything like a theory, I would merely suggest the following explanation.

Between a maximum and a minimum of solar activity there is a well-known period, lasting more or less $11\frac{1}{3}$ years. It is subject to some variations, but on the whole is fairly regular. But besides this short period there seems to exist another, much longer, and as yet less clearly defined, extending over periods to which a length of from 50 to $55\frac{1}{2}$ years, or a little more, has been given. More recent observations favour the longer duration. Such being the case, it is evident that the maxima and the minima of this period must interfere with the manifestations of those of the other, and introduce an element of apparent irregularity, sometimes accentuating them, sometimes tending to their obliteration. For the sake of simplicity we shall indicate in what follows, as *long* maxima and minima, those of the long period, and as *short*, those of the other.

Solar spot observations, anterior to 1750, though they have been preserved and even tabulated at least as far back as 1700, are not numerous and reliable enough to be taken into account in the study of the present question. In justice to them, however, it must be added that the indications they give agree very well with those furnished by other more recent observations.

During the long period a recrudescence of smaller intensity seems to take place between limits of twelve to fifteen years after the long maximum; a peculiarity similar to that observed during the short period a little less than two years after its own maximum. The long minimum, as that of the short period, comes gradually, and seems to be reached some forty years, more or less, after the maximum. The ascent is then rapid. The tables at hand point to a considerable interference of the long maximum with

the short minimum between 1774 and 1776. The minimum is raised almost to the level of some other maxima. The years 1836–37 saw a coincidence, or quasi-coincidence, of the two maxima, and the corresponding solar activity was remarkably high. Nearer our own times, the same occurred again in 1882–83. Many may still remember the numerous and exceptionally large spots seen at that time, not a few of them being visible to the naked eye. On the other hand, the short maxima of 1815–16 and 1828–29 were extremely low. The maximum of 1828–29 deserves special notice: it comes a good two years late. Now, the long minimum must have occurred at that time, about 1824, and may easily have interfered with the manifestation of the true short maximum. A spurious one resulted later on from the rapid diminution of the depressing influence. Of course, when dealing with periods of such length, the number of observations at our disposal is very limited and allows of little more than conjectures.

The present year, which tends towards the minimum, is only sixteen years distant from the last coincidence of maxima, and it has been said that there are signs of revival of activity in the long period some fifteen years after the long maximum. Could not this suggest an explanation of the irregularity noticed? If this hypothesis be the true explanation, the Sun, as a whole, would tend to quiescence, as seems to be indicated by the nature of the chromospheric spectrum; but temporary disturbances and a local increase of activity would result from the intervening influence of the recrudescence following the maximum of the long period.

Conclusion.—Though this is but a suggestion which I hazard with the greatest diffidence, it must be said that the spots themselves seem to furnish arguments in its favour. Though pretty numerous, and sometimes of fair size, they are not generally as lasting as maxima spots, and seem to come in intermittent outbursts, the spotless, or all but spotless days, being by no means scarce. Moreover, and this is more significant, they occupy as a rule low latitudes, though a few exceptions may be noticed. This is established by the spot observations taken at St. Xavier's College Observatory, Calcutta, and which its director, Rev. C. De Clippeleir, S.J., kindly placed at my disposal. It is a known fact that at a time of minimum the latitude of the solar spots is low, and that as

soon as there is a real, and not merely an apparent, revival of activity, there is a sudden transfer of them to higher regions, towards latitude 30°, in both hemispheres. From that moment, though the maximum be not attained, there is a constant decrease of latitude till the minimum is reached again. At this time the spots are again mostly seen near the equator. No sooner, however, has the minimum passed, and the increase begun than the spots suddenly return again, without transition, to their highest position. As the latitude of the large majority of the spots is low this year, they may be classified as minimum period spots; while their number and the several sporadic ones whose latitude is higher testify to the existence of a solar disturbance, due, not to a real and general revival of activity, but to accidental causes, which may mask to a certain extent but not suppress the tendency of the Sun, as a whole, to greater quiescence.

Let us also recall in connection with this question the wealth of the corona in polar wisps, one of the features of a corona belonging to a minimum period, and the tendency it had to exhibit some other characteristics of the minimum type.

METEOROLOGY.

We give below the meteorological data gathered by the Rev. E. Francotte, S.J., the member of the party in charge of this department. The results obtained by the observers of other concomitant phenomena have already been sufficiently mentioned in the description of the eclipse.

The clearness of the atmosphere was all that could be desired on the days preceding January 22, though the 21st was somewhat hazy, and a few cirro-stratus were observed to the west on the three previous days; on the 19th they covered about one-tenth of the sky. The early morning of the day itself showed a slight haze, which was soon dispelled by the solar rays. Not a cloud was visible as the time of the eclipse drew near, and the air was calm; the temperature being then 76·3° F. in the shade and 80·8° in the full sunshine, and the pressure 29·850 in. No perceptible effect on the temperature was at first perceived, and both the shaded and

unshaded thermometers continued to rise steadily till close to the time of first contact. At 12h. 30m. (Dumraon time) the readings were 76·6° and 81·7° respectively. From that moment till 12h. 45m. a slight fall to 76·2° and 81·5° was noted. At this time the quietness of the atmosphere was disturbed by sudden and rather strong puffs of wind from the south-west, which caused some anxiety to the observers; but after a few minutes all was calm again. Then began a rapid descent of the thermometric columns, but less accentuated in the shade, till, at 13h. 45m., a few minutes before totality, the indications were 72·2° and 74·8°. During this time, at 13h. 30m., there were more puffs of wind, of short duration, from the west-south-west. The next quarter of an hour, near the end of which totality took place, witnessed falls of 1·5° and 5·0°, and at 14h. the temperatures reached were 69·2° and 69·8°, a difference of only ·6°. At 14h. 15m. the shaded thermometer went down to 68·8°, the lowest temperature it recorded, while during the same period, for some unexplained cause, the other rose 1·2°, to fall again and attain its minimum 69·0° fifteen minutes later, at a time when the shaded instrument had already risen to 70·6°. From 14h. 30m., under the action of the reappearing Sun, the ascent was rapid, and 72·6° and 77·7° were registered at 14h. 45m., about half an hour before last contact. A further but slower rise took place till 15h. 25m., some ten minutes after the end, and 75·2° and 80·8° were attained. A fall of a little more than one degree was then noticed in the sunshine, while the shaded thermometer remained steady. At 16h. a somewhat curious rise of ·3° in the shade and of ·9° in the Sun took place. From this moment the regular afternoon fall began, and at 16h. 45m., after which observations ceased, the temperatures noted were 73·8° and 76·6°. At 16h. 20m., a slight wind rose from the north-west, and in the evening there was a thick mist.

Barometric variations were slight, the difference between the maximum and the minimum pressures during the eclipse being only ·052 in. A large part of this depression, if not the whole, must be attributed to the diurnal range, the minimum of the day in the second half of January at Dumraon falling very nearly at 16h. No appreciable change in the original pressure, 29·850 in., took place before 13h., between which and 13h. 15m. a fall of ·004 in. occurred; this was followed by the puffs of wind mentioned above, but the pressure remained unchanged till a few

minutes before totality. A little after 13h. 45m. a steady fall began, rather rapid between 14h. and 14h. 15m. The minimum, 29·799 in., was reached at 14h. 30m., at the same time as the minimum of the unshaded thermometer, and obtained till 15h. 40m., nearly twenty-five minutes after the end of the eclipse. Then the pressure rose slowly, and attained 29·830 in. at 16h. 25m., no further change occurring up to 16h. 45m., when observations ceased.

The aneroid used had previously been carefully compared with a standard mercurial barometer, and with quite satisfactory results. The curve of Plate XIV. gives the readings without corrections for altitude and temperature. The thermometers were two identical and very sensitive instruments, constructed for meteorological purposes. The difference between their readings for the same temperatures was found from over forty comparisons to be not greater than ·05°. They read ·5 lower than the Kew standard. The temperature given above and in the curves of Plate XIV. ought consequently to be increased by half a degree.

CHAPTER VI.

OTHER STATIONS.

The great dearth of details to hand makes it extremely difficult to give more than a short account of the programme of work which each of the observing parties undertook in the several stations they had selected. Little by little information keeps dribbling in, but it will very likely take at least a year before anything complete and definite can be gathered from the results obtained. The photographs taken have to be studied and compared, careful and delicate measurements to be made, and numerous laboratory experiments to be devised and performed. We shall, however, summarise what has been made public up to this time, supplementing it by other data obtained through private correspondence. The most important posts of observation will be reviewed in succession.

JEUR.

It is from Jeur that information is most abundant. Four parties had taken up their quarters in or near this locality. Besides what has been published in various Indian newspapers, and especially in the 'Times of India,' we gather the following details from a letter of the Rev. F. X. Haan, S.J., of St. Xavier's College, Bombay, who belonged to the party organised by Prof. Naegamvala, of the College of Science, Poona.

The Poona party.—The camp of this party was $2\frac{1}{2}$ miles from the central line of totality. The chief instrument used was a large prismatic camera. An equatorial, mounted on a massive pillar, ten feet high, had its 6 in. lens stopped to four. In front of it were hung two glass prisms, of such high dispersive power that the telescope had to be

turned as much as 120° from the Sun. Professor Thomson was in charge of the apparatus.

Next to it was a clock-driven 12-in. cœlostat, destined to distribute light to three spectroscopes, one of which was in quartz, the others in spath. Prof. Woodrow and other members of the College of Science, were entrusted with them. Besides these, there was in charge of Mr. Hudson a 12-in. mirror mounted on a new principle by Dr. Common. Its purpose was to give light to an 8-in. telescope, placed horizontally, and connected with a photographic apparatus. The image given by it is about one inch in diameter. Another photographic camera, giving much smaller but brighter images, was behind it, and next to this was erected the shed for meteorological observations.

In front was a series of smaller telescopes. The first was placed under the care of Rev. F. X. Haan, S.J. The task of the observer consisted in noting the changes perceived in the solar spectrum. At the second instrument was Prof. Rishi, of the College of Science, who had to look for white prominences. Near him was stationed the Rev. — Mackichan, with a spectroscope of great dispersive power. Then came a spectroscope with long collimator, destined to take a photograph of the total solar radiation ; it was under the care of Mr. Sauga.

Forty photographs were attempted on the whole, and the expedition seems to have been altogether very successful. Amongst other important results, we are given to understand that good negatives of the flash spectrum have been obtained. Several other observers were told off to secure drawings of the corona, to note the effects produced on animals, to observe the shadow bands, and record several other miscellaneous phenomena.

The following is borrowed almost textually from the account of his own observations communicated by the Rev. Fr. Haan to the 'Bombay Examiner.' His business was to observe the variations of the spectrum before, during, and after totality. For this purpose he made use of a Stewart equatorial, to which had been adapted a slitless direct vision spectroscope with five prisms. We quote from the article :

'The first change took place at 1h. 4m. 17s. (Up to this time the spectrum had been continuous and devoid of dark lines.) Then slowly the three lines *b*, E, and F, made their appearance, and grew steadily darker

and darker. Gradually more lines became visible, and at 1h. 17m. 29s. all the lines could be distinctly seen as in the ordinary solar spectrum of the slit instrument.

'The spectrum, which up to this had filled the whole field of vision, now began to shrink, and at the same time the lines D_3 and F began to project, the projecting lines being of a bright yellow and blue. Then the spectrum slowly vanished. When it was three-fourths of its original breadth other lines began to project, but not as high as D_3 and F; and when the breadth was reduced to one-fourth, most of the dark lines of the spectrum were projecting, but they were not all of the same height, and some had no projection at all; E and *b* were rather high, yet had only half the length of D_3 and F. Several lines of 520 to 525 wave-length were much shorter than *b*, and I observed the same of several others between *b* and F. If this observation is correct, it tends to prove that the substances of the solar atmosphere are not equally distributed; for the shorter lines must belong to materials present only in its lower layers.

'Next came the vibration of the shadows, which announces the *flash*. The impression is similar to that experienced by a traveller in a fast train watching, through the window of his carriage, the sudden transit of objects along a trellis-work, the openings of which get narrower and narrower till they finally disappear.

'Just before totality I could still see the bright lines, but not as distinctly as before. I kept my eye fixed on one part of the spectrum: a group of lines between 500 and 505 wave-lengths. The flash is the moment when the continuous spectrum of the Sun disappears, and the dark lines become bright throughout.

'When the flash set in only three-fourths of the lines in the group upon which I had fixed my eye were bright.

'Most fortunately, Prof. Naegamvala has succeeded in the most difficult task of taking a photograph at this important moment. This will no doubt be of the greatest use, for it is very difficult for any observer to see a weak thin line at the side of a bright one, especially when the time for observation is less than a second, as the duration of the flash seemed to be to me.

'After the flash there was complete darkness; only the bright arcs of D^3 and F remained visible, and in the middle of the field of vision appeared

a luminous, greenish, broad arc, which was at first weak, and then grew steadily in brightness and extension. This was the line 1474, the light of the corona.

'The two arcs D_3 and F were of a dazzling light, and four large prominences appeared nearly equidistant from one another; two of them about 20° of the Moon's line of motion: the one above, the other below it; and two at a distance of about 40° and 50° respectively in the upper and lower parts.

'One of these prominences, that which appeared nearer the line of motion towards the north, showed a continuous spectrum for the first five or ten seconds. It was difficult to distinguish the colours, and lines could not be distinguished at all. A clearer observation of this phenomenon would have been of much importance, for it is only when the lines are visible that we can determine whether the spectrum does or does not belong to the prominence. A star near the Sun, in the proper position, can produce the same effect, even though it is not visible to the naked eye.

'If, after all, the spectrum did belong to the prominence,[1] it would prove that the lower part of the chromosphere was lifted to a certain height by the eruptions which produce the prominences. We have still to learn whether any of the photographs taken during the first seconds show a similar spectrum.'

The observer then goes on to describe some of the peculiarities of the prominences observed on both sides of the point of first internal contact, and remarks that the similitude of their form in the C and D_3 lines show that hydrogen and helium were equally distributed in them. He then notes the steady growth of the coronal light, and continues:

'For a few moments I watched the coronal light; it seemed steady. Whilst I was still engaged upon this observation, suddenly a very bright continuous spectrum, about one-tenth of the breadth of the Moon, shot like a flash of lightning through the field. I had to remove my eye from the instrument. The totality was over.'

[1] It has been seen in the account given in the preceding chapter of the spectra obtained at Dumraon, that not only is this observation correct, but that a similar continuous spectrum corresponded to each of the prominences contained in the short metallic arcs, and perhaps also to the large one at the west. On the photographs, however, the prominence lines are easily distinguished from the weaker spectrum on which they are projected. The fact that the phenomenon is repeated at each prominence excludes the possibility of star intervention. Similar photographs were obtained at Kalni by Mr. Evershed.

Prof. Apte took several interesting observations of the visibility of the planets. They may be useful to determine the intensity of the coronal light.

The Lick Observatory party.—To the left of Prof. Naegamvala's camp was the Lick Observatory party, under the direction of Prof. W. W. Campbell, who came to India accompanied by Mrs. Campbell and Miss Beans. His appeal to local scientific volunteers was not in vain, and amongst other helpers were included Captain Fleet, R.N., Major Comfort, Consul for the United States, and Mrs. Comfort, Major Boileau, R.E., Lieutenants Kinnahan, R.N., Mansergh, R.N., Corbett, R.N., Mr. Garwood, R.N., and the Rev. J. E. Abbott.

His principal instrument was a 40-feet telescope, or rather a 5-in. lens of 40 feet focal length. One end of the tube rested on a masonry tower 23 feet high, surrounded by a wooden structure covered with canvas, to protect it against the action of a possible strong breeze. The other end was let into a pit 10 feet deep, in which was erected, on a solid iron frame, a tent-like camera large enough to admit several persons. A support firmly fixed in the ground carried the plate-holder, on which the plates were moved by clock-work during exposure. The operators were inside the camera, and could follow step by step the progress of their work. The lens was not connected with the tube, but was fixed on the tower itself, so as to be perfectly independent of any accidental vibration of the body of the telescope. Captain Fleet, assisted by Mr. Garwood, was in charge of the instrument. The plates used seem to have been of 14×17 in., and twelve exposures were secured, giving solar images of $4\frac{3}{8}$ in. Three instantaneous exposures were given to record the prominences and the inner details, and the others were twos of one, two, four, and eight seconds respectively, and one of sixteen seconds. In the last case Prof. Campbell expects the corona to cover the whole plate, and perhaps overstep it.

Near this instrument was a square wooden tube tilted at the latitude angle of the place, and revolving round its long axis by means of a cord wound round it, and supporting a weight. The fall of the weight was controlled by clock-work. Two telescopes of smaller size and three spectroscopes were strapped on to this tube, and were destined to take spectroscopic coronal and chromospheric photographs, and smaller and brighter pictures of the corona, showing details in its outer portion.

On an ordinary equatorial stand, half buried in the ground, were fixed two other very powerful spectroscopes, intended for similar purposes. All the plates were moved by clock-work, to reduce the number of assistants and lessen the chances of errors.

According to Prof. Campbell, about a year will be needed to work out his results fully. Two of the main problems he had in view were the determination of the rotation of the corona, and the presence or absence of calcium vapours in its constitution.

The Japanese party.—A few hundred yards to the east of Prof. Naegamvala's party were the Japanese, under the direction of Professors Taero and Hiramaya. They had two telescopes with them; the first, 36 feet long, was horizontally mounted, and received light from a cœlostat; the other was an equatorial. Their photographic observations do not seem to have met with unqualified success.

The Chabot Observatory party.—Two miles further south, near Wangi, was the Pevison Expedition, under Mr. Ch. Burckhalter, from the Chabot Observatory, California. His instruments were two telescopes fixed on the same equatorial stand. They were identical, and of a length of about 15 feet; but the first was entirely worked by hand, the other by electricity. An ingenious contrivance of Mr. Burckhalter's invention allowed of different lengths of exposure for the different portions of the corona on the same negative. It consisted of a disc, placed in the instrument itself, and rotating round an eccentric axis at a short distance from the plate. By its means short exposures could be given to the bright coronal regions, and be graduated at will for the others.

VIZIADRUG.

We are indebted for the following details to some private letters, and to the eclipse correspondents of various Indian newspapers.

The First R.S. and R.A.S. party.—The expedition which occupied the old Viziadrug Fort was one of those sent by the Royal Society and the Royal Astronomical Society. It was led by Sir Norman Lockyer, helped by his son, Dr. W. J. S. Lockyer, and Mr. A. Fowler, Sir Norman's

assistant. They were joined by Lord Graham, Mr. Eliot, head of the Meteorological Department of India, Prof. Pedler, of the Presidency College, Calcutta, and some other gentlemen; they had, moreover, the help of 150 of the officers and men of H.M.S. *Melpomene.* Their chief means of observation were the following instruments: a $3\frac{3}{4}$-in. equatorial, of which Sir Norman himself, with Midshipman Bourne as general assistant, took charge; a 9-in. prismatic camera, under the management of Dr. W. Lockyer; and another of 6-in., fixed horizontally, entrusted to Mr. Fowler. Prof. Pedler was at a 6-in. equatorial armed with a powerful grating spectroscope. One of his tasks was to look for bright lines, especially those of iron and carbon, in the lowest coronal regions. Towards the end the spectrum of the outer corona was examined. Another member of the party was detailed to the charge of the polariscope. Staff-engineer Kerr and Lieutenant Quayle respectively manipulated a coronograph and a photographic integrating spectroscope; while Lord Graham and others managed two cinematographs, one for the eclipse and another for the shadow. A boat was sent out to sea about two miles off for shadow observations; six discs of different diameters were set in position, about 20 feet high, for eye observations of different coronal regions, and Lieutenant Blackett was put in charge of the star observing party. With him were also the draughtsmen selected for sketches of the corona, and scattered at different points of vantage were others detailed for observations of various secondary phenomena. Several other slit and slitless spectroscopes were used by different members of the party.

Mr. Eliot had established his principal station at Viziadrug. He had made careful and elaborate preparations for as complete a meteorological record as possible, and for this end had given instructions to the various meteorological observatories studding the whole extent of India, to the number of nearly two hundred. The results will be published in the 'Indian Meteorological Memoirs.'

At Viziadrug, as everywhere else, the fall of light was less than expected, but the appearance was quite different from the shadows of twilight. The landscape looked as if seen through coloured glasses. The advent of the Moon's shadow was scarcely perceived; there was a violent quivering of the atmosphere, and a sudden deepening of the darkness.

From all accounts, the expedition seems to have been eminently

successful. Of course, few details can as yet be known about the results obtained; but we shall quote the opinion Sir Norman Lockyer himself expressed to a representative of the 'Times of India':

'We were hard at work at Viziadrug until Monday afternoon, by which time our plates were developed, and the results we found were admirable, with the exception of the integrating spectroscope. Through some accident the slit in that instrument became closed, and we got nothing from it at all. We have roughly estimated already that the number of lines photographed in the spectrum of the chromosphere exceeds a thousand, and the various strata of the solar atmosphere are revealed in four continuous series of photographs, both at the beginning and the end of totality, which is almost beyond our utmost expectations. We also found that the coronal rings were entirely separated from the chromosphere; that the stems of the streamers even are visible in the coronal rings, whereas the prominence rings are most intense where the corona is least intense, so that this points to a different *locus* of origin. Yes, I think you may say that we have made a very considerable advance indeed.'

In his account given before the British Astronomical Association at the meeting of April 27, Mr. Fowler mentioned that the 1474 ring looked of unequal brightness at different points. The general outline corresponded to that of the inner corona, the brightest part of which appeared quite distinct from the long streamers. We learn also that Prof. Pedler observed several iron rays in the lowest layers of the corona, and that no enhanced lines were seen in the chromospheric spectrum. Lord Graham seems to have been successful with his cinematograph so far as the eclipse itself is concerned; unhappily, owing probably to the climatic effects upon the woodwork, the film was badly fogged. Of course there was no question of taking pictures of the advent of the shadow.

SAHDOL.

Sahdol, in Rewah, was favoured by the visit of two scientific expeditions.

The Second R.S. and R.A.S. party.—With the Astronomer Royal, Mr. W. H. M. Christie, were, amongst others, Prof. H. H. Turner, Dr. A.

A. Common, Major Burrard, R.E., Lieutenant Crosthwait, and a Trigonometrical Survey party. The programme was almost exclusively photographic, and specially directed to pictures of the corona on a large scale. Mr. Christie used plates of 10 × 12 in.; seven plates were exposed during totality and twenty-four before and after. On these the lunar disc was 3½ in. in diameter. Prof. Turner took coronal photographs on a scale varying from ½ to 1½ in. Twelve of them were taken during totality, and to these must be added two obtained with polarised light. All the negatives were very satisfactory. The end the Astronomer Royal had in view in securing the partial eclipse photographs was the accurate measurement of the Moon's motion during the eclipse. The instruments used were large coronographs with cœlostats. The Astronomer Royal took up his position in a dense jungle, in which a clearing had been made for the occasion.

The Madras Observatory party.—Prof. Michie Smith's assistants were Professors Moss and Jones, Doctors Evans, Van Geyzal, L. Campbell, Slater, and a number of other gentlemen. This party has also good reasons to be highly satisfied with the results obtained. Seven large negatives secured by Prof. Michie Smith at the 40-feet telescope, ten other heliographic pictures, four coronal spectra obtained by Prof. Moss, and numerous drawings of the corona, executed by General Strahan, Sir Thomas Holditch, General Woodthorpe and Colonel Barr, and others, are a record of which even a Government Astronomer may well be proud. Prof. Michie Smith intended making three classes of observations. The following description of his instruments is borrowed from a correspondent of the 'Pioneer':

'1st. For taking photographs of the corona he uses a polar-siderostat having a focal length of 40 feet, giving an image 4 in. in diameter, on plates 18 in. square, held in a rotating holder. There is no small difficulty in setting up this instrument, as it has to point to the north pole, necessitating the elevation of the huge telescope to an angle of about 23°, for which purpose a mound some 17 feet high has had to be constructed. On the top of this mound is placed the mirror reflecting the coronal rays in the 6-in. object glass of the telescopic camera.

'2nd. An equatorially mounted photo-heliograph having a 4-in. lens especially intended to photograph the most attenuated streamers of the corona. The image of the eclipsed Sun in this case is much smaller than

in the case of the polar-siderostat, but the distance to which the field extends is much greater, so as to embrace, if possible, the most extended part of the corona from the Sun's edge. The instrument has a special plateholder containing twelve photographic plates, arranged round the edge of a disc, which is rotated through 30° to expose each plate in succession. Thus, during the total phase, it will be possible to take twelve pictures. As the exact exposure necessary to produce good results is not well known, the plates will be exposed for varying times, so that among them there may be some with the proper exposure.

'3rd. For spectroscopic work he will use a spectroscope originally designed for the study of the zodiacal light, a subject to which he has given special attention. The prism is of calc-spar, and all the lenses of quartz, these materials being much more transparent to photographic rays than glass.'

The extent of the streamers on some negatives reaches two lunar diameters. Meteorological observations were also taken. During the eclipse the wind died away and the temperature fell eight degrees. It was also observed that birds were visibly affected; partridges, for instance, began to call loudly.

PULGAON.

The Third R.S. and R.A.S. party.—Pulgaon, near Wardha, was selected by another expedition sent by the R.S. and R.A.S. It consisted of Mr. Newall, of Cambridge, and of Captain Hills, R.E. They received the help of Captain and Mrs. Lenox-Conyngham, Lieutenant Beazeley, Mr. Blennerhasset and others. Their programme was chiefly spectroscopic. 'The eclipse observations at Pulgaon,' says a telegram of January 23, 'were very successful. Twelve photographs of the corona and twenty-four of the spectrum were obtained. All photographs which were developed of the picture of the corona were excellent.' Such were the first informations wired to the outer world.

A determination of the distribution of coronium through the corona was attempted by Mr. Newall. As far as could be seen, no rifts were.

detected in the green ring, which had a depth of about 5′ or 6′, but one or two apparent extensions of the gas were noticed. Captain Hills obtained records of the flash, both at the beginning and at the end of totality, which furnish a complete series of the changes observed at different chromospheric altitudes. The weakness of the coronal spectrum prevented the solution of a problem to which the attention of observers had been directed: the rotation of the corona. The question to be decided is whether the corona has a proper independent rotation or not. From his observations during the eclipse of 1893, M. Deslandres came to the conclusion that the coronal rotation did not differ from that of the photosphere. To test the correctness of this opinion, Mr. Newall had arranged a specially disposed spectroscope with a double slit, the slits being tangential to the opposite limbs of the Sun, one of them stretching from the solar equator northwards, the other from the other end of the equator southwards. The collimator of the instrument was parallel to the polar axis. The faintness of the light prevented the attainment of any satisfactory result.

TALNI.

The First B.A.A. party.—Talni is a small village near Amraoti, in the Central Provinces, selected by an expedition sent by the British Astronomical Association. This party consisted of Mr. and Mrs. Maunder, Mr. Thwaites and Mr. Evershed. They were joined by Captain Molesworth, Mr. J. W. Backhouse, Mr. Sharp, and Mr. V. Smith. A telegram sent to the newspapers shortly after the eventful day runs: 'The air during the eclipse was very clear, and the observations successful; many photographs were taken with telescopes and spectroscopes.' The general lines of the programme were very similar to those of the other stations—photographic pictures of the corona, and spectrophotographs of the corona and the chromosphere. Mr. Thwaites, in the 'English Mechanic' of March 4, estimates the length of the south-western streamer at two and a half lunar diameters.

Mr. Maunder observed conjointly the corona and its spectrum by means of a pair of binoculars, one eye-piece of which was fitted with a

prism. From his own account, given at a meeting of the B.A.A., we learn that the green coronal line was seen to form a continuous ring without rifts and rays, confirming the opinion that coronium exists under similar circumstances in bright and dark coronal spaces, a fact already noticed in 1893, and which seems to indicate that the difference of illumination is not due to a want of continuity. This green ray could be followed up to some 6 feet from the lunar disc. Shortly before and after totality, when the solar crescent was reduced to a mere thread and acted as a slit, Fraunhofer's lines became visible as arcs, the extremities of which were first reversed. Then the continuous solar spectrum, much narrowed, broke up into several linear ones, constituting the spectra of the portions of the photosphere still visible as Baily's beads, and as they disappeared the reversing of the absorption lines took place. Similar phenomena, in reversed order, took place at the end of totality.

Mr. Maunder and Captain Molesworth took photographs for the special purpose of obtaining the greatest possible coronal extensions. They had two cameras attached to a Waters equatorial, lent by the Royal Astronomical Society. The first had a $1\frac{1}{2}$-in. Dallmeyer lens of 9 in. focal distance; the object glass of the other was a portrait combination of nearly $2\frac{1}{2}$ in. aperture, with a telephoto-lens magnifying up to over eleven diameters. The solar image obtained had a $\frac{7}{8}$ in. diameter, and in spite of the excessive enlargement a fair amount of details was obtained. The long exposures of twenty seconds with the Dallmeyer camera gave very satisfactory pictures, in some of which the four main streamers can be followed to distances of 3, $4\frac{1}{4}$, $4\frac{1}{2}$, and 6 lunar diameters respectively. A specially interesting result was obtained with a plate exposed in the Waters camera some three minutes after totality. Of course, the crescent was strongly solarised by long exposure, but the entire dark disc of the Moon surrounded by a coronal fringe was photographed, showing the possibility of making some use of partial eclipses for the purpose of coronal photography.

The work of Mr. Evershed and his assistants was spectroscopic. His three photographic instruments were a prismatic camera, a slit spectrograph, and a large slitless spectrograph mounted on a 6-in. telescope; to these must be added an equatorial fitted with a solar spectroscope, and a heliostat destined to give light to the prismatic camera and to the slit spectrograph. This last instrument gave him one negative, the prismatic

camera a series of ten, and the slitless spectrograph two. In the series of ten were three photographs of the flash spectrum, one at the beginning and two at the end of totality, and four showing Fraunhofer's dark lines. The exposures began twenty seconds before totality and ended eighteen seconds after it. All these photographs have a considerable ultra-violet extension.

The remarkable linear prominence spectra, mentioned in the description of those obtained at Dumraon, were also registered on Mr. Evershed's photographs. We borrow his own account of the phenomenon from the 'Monthly Notices of the Royal Astronomical Society, March, 1898':

'Plate No. 4 was given an instantaneous exposure, a few seconds after totality had commenced. It shows simply the ordinary chromospheric spectrum; but there is a curious feature in the prominence spectrum which is well brought out in this photograph. In the extreme ultra-violet, most of the prominences give an apparently continuous spectrum. This appears to commence abruptly at about λ 3660, at the point where the hydrogen series ends, and it extends in an unbroken line to the end of the plate, at about λ 3390.'

On our Dumraon photographs these spectra are already faintly perceived before F, and fade away in the purple towards H and K. Differences in the nature and time of exposure of the plates may easily account for this divergence. On a negative which Mr. Evershed exposed for thirty seconds, the arcs are crossed by these narrow streaks of continuous spectrum.

With regard to the question of the relation between the bright lines of the flash spectrum and the dark Fraunhofer lines, without intending to draw definite conclusions, Mr. Evershed is led by a study of his negatives to an opinion similar to the one we expressed in Chapter IV. According to him, the main part of the absorption probably takes place within a few miles only of the photospheric clouds, though he does not exclude the possibility of a similar action within or between them.

BUXAR.

The Second B.A.A. party.—The Rev. J. M. Bacon, of the B.A.A., went to Buxar, where amongst his supporters were Mr. H. Moore, Mrs. W. Nicholson, and Miss Dixon. His work is reported to have been very

successful, and he secured with his cinematograph a good record of the eclipse. Unhappily it seems that Mr. Bacon's boxes were tampered with on his arrival in England, and his film stolen. Let us hope, for the sake of the observer and in the interest of science, that the thief will be apprehended.

Miss Dixon, assisted by Miss Bevan, noted the clearness of Fraunhofer's lines immediately before and after totality; they remained visible for about ten seconds. Colonel Sinclair observed the coming of the shadow from a height of about fifty feet, and describes it as almost instantaneous, while Mr. Johnson remarked that there was in the advent of darkness a pause followed by a sudden leap into gloom. After third contact the lunar disc was clearly seen in its entirety projected on the corona. Miss Bacon took a number of pictures of the eclipse, and made a series of photographic tests of the return of light after totality.

GHOGLEE.

Dr. Copeland's party.—Dr. Copeland, Astronomer Royal of Scotland, had settled at Ghoglee, not far from Nagpore. From what we have seen of the reproduction of his coronal photographs, his attempts in that line have been successful, but details about his work have not as yet reached us.

DUMRAON.

The Survey of India party.—The Photographic Department of the Survey of India had organised an observing party, of which Mr. Pope, the Head of the Department, took charge. His assistants were Messrs. H. Haward and T. R. Theakston. They were joined by Messrs. C. Little and G. W. Küchler, of the Presidency College, Calcutta. Their instrument was a photo-heliograph driven by clock-work. The lens was a large doublet by Dallmeyer, with a focal length of about thirty inches. The

results obtained by the expedition have been published by Mr. Pope in his Report on 'The Total Solar Eclipse, January 22, 1898, as photographed at Dumraon.' They took seven photographs of the corona with exposures varying from one to twenty seconds. The measure of their success can be gauged by the beautiful coronal picture illustrating the Report. The negatives were sent to the Joint Permanent Eclipse Committée of the R.S. and R.A.S., on behalf of which the observations had been taken.

HINDU WAY OF LOOKING AT AN ECLIPSE.

Eclipses, both solar and lunar, are amongst India's greatest blessings. Rahu is a grand sanitary commissioner, and some have gained a C.I.E. for less important services. Take a walk through the native quarters of any large town on an eclipse morning. Cast a look, though not a long one if you want your breakfast, on those broken pots and pans heaped everywhere, and be thankful that your last meal was not cooked in them, as was that of the family living in the next hut. If you have a vote, you may be tempted to give it to Rahu, if he stands for your ward at the next election, and you might do worse than insist on having him on the Sanitary Board, on condition that he comes round once a month or so.

Who is Rahu? Rahu is, unhappily, a sorry fellow, a sad character, some kind of bad genius in the shape of a horrid dragon, or huge serpent, or something of the sort, a lover of darkness to hide his wicked deeds. The Sun and the Moon trouble and enrage him by bringing his nefarious projects to light; hence Rahu has more than one grudge against them. The artful dodger tries now and then to work his schemes in one or other of the luminaries, nay, even to swallow up altogether his old rivals and enemies. They naturally object to the process, and then there is a struggle. But it seems that they would come off only second best, were it not that the ferocious Rahu is an arrant coward, frightened by noise. He has, moreover, a soft side to his otherwise hardened nature. He cares for his friends, and is thankful for favours granted them, even to the extent of sacrificing his own revenge for their benefit, which is more than can be said of many who bear a better name. In consequence, whenever

it is known that Rahu is on the war-path and intends having a bite at the Sun or the Moon, great preparations are made against his advent. Such is the wickedness and evil influence of this fearful monster that, for some cause or other which is not very clear, his mere appearance is enough to pollute anything that man or woman has used, and these things have accordingly to be either thoroughly cleansed, given away, or destroyed. Cooked food falls under the same ban, though, as a concession to the Indian palate, an exception is made in favour of pickles and preserves, of which a provision has been laid up for the year. These may be protected against pollution by the insertion of some leaves of the sacred tulsi plant. And here, in spite of all his evil works, Rahu comes as a benefactor. Old, grease-sodden, earthen pots are broken, vessels which would have done duty till they fell to pieces, or till the next Dewali festival (another of India's blessings in disguise). Brass pots are vigorously scrubbed, old clothes are piled up in a corner for the benefit of beggars, while the house comes in for a thorough cleaning, of which it is often sadly in need.

Rahu arrives on the scene, but the people are ready. Gongs, tom-toms, bells, sacred conch-shells, horns of sorts, and brass utensils of all kinds are at hand, and he is greeted by such a fearful din that, even were he not a coward, it would be more than enough to put him to flight if he had any regard for his tympanum. Then, especially in southern India, out come Rahu's *protégés*, the Pariahs, those despised outcasts of the Indian community for whom he keeps a soft corner in his savage heart. They overrun the streets, shouting 'Give us alms, and release the god,' and they carry baskets and bags which are soon filled and swollen by repeated doles of parched rice and other food, and gifts of copper coins and cast-off garments.

But Rahu is obstinate. He is very probably enraged at the discovery or prevention of some pet wickedness on which his mind was set, and so the devouring process goes on. Then the din and clamour increase, as do the gifts to the beggars; and at last Rahu's heart is touched, or perhaps his head is split by the infernal noise. He gives up his more than half-won victory, and the disgorged Sun or Moon comes forth, as bright as ever. But one has an idea that Rahu is not half so black as he is painted, that he is but a humbug fond of questionable practical jokes, and enjoying the fun of the fright he causes. His swallowing the Sun or the Moon is a

mere sham, and he merely crawls over them, making believe that he is eating them up; a poor deceit, indeed, as is patent to those who look at him from some distance to the right or to the left, and see parts of poor Suraj's or Chand's body underlying his.

Beyond the fear of losing their diurnal or nocturnal luminary for good, which would already be bad enough, the current belief amongst many Hindus is that dire calamities are sure to follow these nefarious attacks, whether caused by the anger of the gods or some spiteful pranks of the baffled Rahu it is hard to say. Amongst the small mercies promised to India for this year was a big earthquake, all over the country, lasting three days, and compared to which the great earthquake of last year was a mere trifle. There were also to be volcanic eruptions on a stupendous scale, by which whole districts were to be destroyed and thousands engulfed. Such was the faith of a large portion of the common people in these predictions, that in some places, at Bombay, for instance, an exodus threatened not inferior to that due to the plague. Why Rahu changed his mind has not been ascertained; perhaps he got interested in the mysterious doings of the many astronomical parties bent on watching his evolutions, and forgot all about his wrath; or again, perhaps he was frightened out of his wits at the queer appearance of so many strange implements all pointed towards him. At any rate, he passed harmlessly on.

Apart from the anxiety caused by impending calamities, a day of eclipse is a hard one for the orthodox Hindu. It is a strict fast day for him, the rule laid down being that the latest meal must precede the eclipse by twelve hours. After this ablutions are prescribed, and the meal is to be prepared and cooked, as nothing of the kind can be done during the eclipse or before purification. When, therefore, he sits down to his long expected meal, he has had a good fifteen hours to digest the last. When the eclipse begins, he takes a bath in some sacred stream or tank, in the hope of securing by these purifying ablutions the protection of the gods against all the misfortunes threatened by Rahu. Then, clad in new vestments, with a white scarf over his shoulders and another wound round his head, he sits on the ground floor till the last contact takes place; listless and woe-begone, trying, likely enough, to possess his soul in patience under the threatening difficulties, while the women of the house

distribute alms to the endless row of beggars that besiege the door. This programme, however, is not always rigorously adhered to, the departures from it being in exact proportion to the degree of heterodoxy of the individual. Among the educated classes these practices are becoming more and more confined to the women folk, though they are still very general in many parts of the country.

The numerous scientific parties who for about a month overran India, bent on eclipse observations, may have helped to dispel some of these curious notions. We have tried to present in a small compass the work undertaken and performed by these several parties, so far as known for the present, and we trust that we have sufficiently shown that it was not without cause that the scientific world was so deeply moved by the advent of the Indian eclipse of 1898. Let us hope their efforts have not been in vain; indeed, there are not wanting good reasons to believe that success has surpassed the most sanguine expectations. The work, moreover, was done under exceptionally favourable circumstances. 'Although,' says the 'Englishman' of January 25, 'on behalf of the sightseers the absence of the sensational features of the phenomenon may be regretted, these apparently adverse conditions were entirely favourable to the work of observation. Indeed, if the arrangement of the climatic programme had been left to the astronomers themselves, they could not have suggested an improvement.' Let us conclude with the appropriate words of a correspondent of the same newspaper, who wrote on the eve of the eventful day to justify the steps taken by the East Indian Railway in connection with the eclipse: 'Probably there will be those who will come back disappointed with the result. They will say that on the whole a total eclipse of the Sun is an entertainment the merits of which, from a spectacular point of view, can easily be bettered by a kaleidoscope, if not by a cinematograph. They will affect to pity themselves for having torn themselves away on its account from the delights of a Calcutta cold season for the space of thirty-six hours; and not until some years have passed, and they find that they have been assisting at an event of first-class importance, which may never recur under similar conditions, will they begin to reflect that after all there is something to be said for science and railway enterprise together.' Let the sightseers, then, who were disappointed by the absence of phantasmagoric effects, console themselves with the reflection that they have

witnessed a phenomenon during which the progress made by science will in all probability rival that of the last half century; and when, as years roll by, the Indian eclipse of 1898 is referred to as marking an epoch in scientific research, they will have the noble satisfaction to think that they were there and witnessed it.

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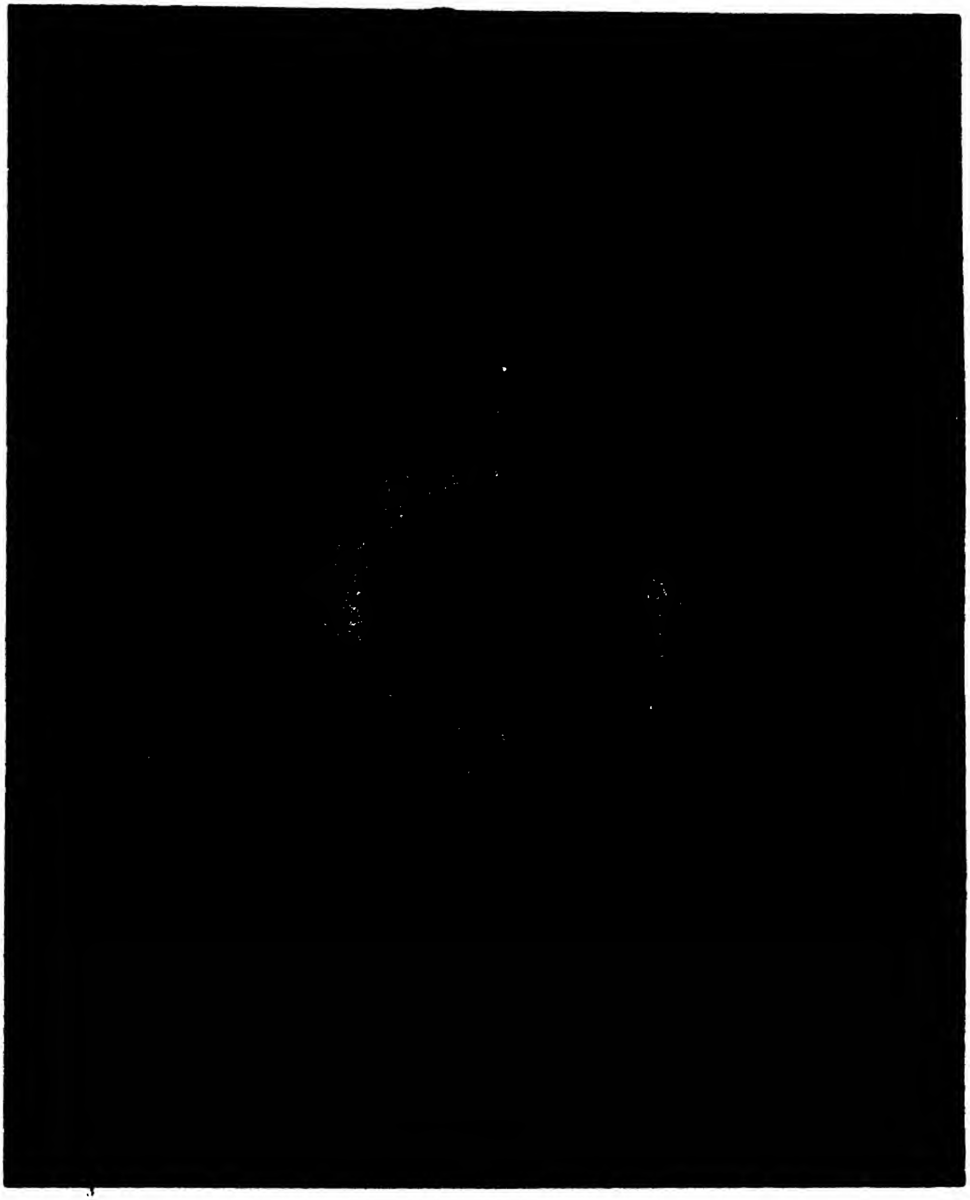
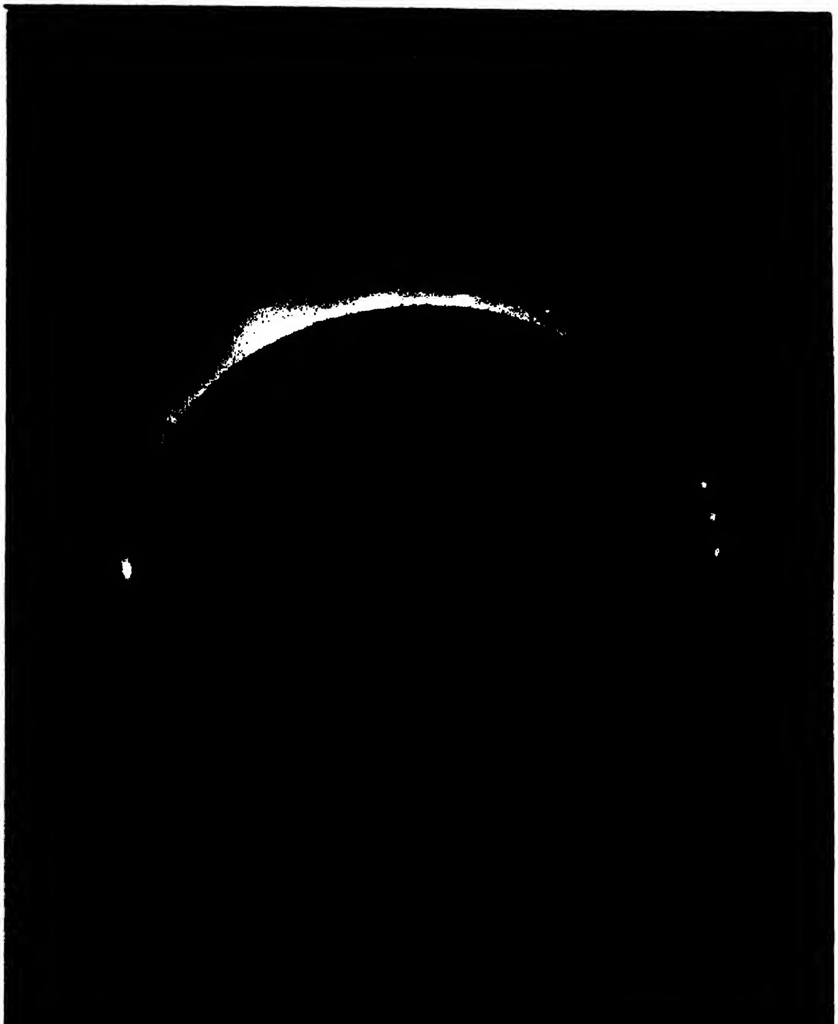
Plate I.



The Corona, at the 73rd Second of Totality.

PLATE II.



The Prominences, at the 10th Section of Totality.

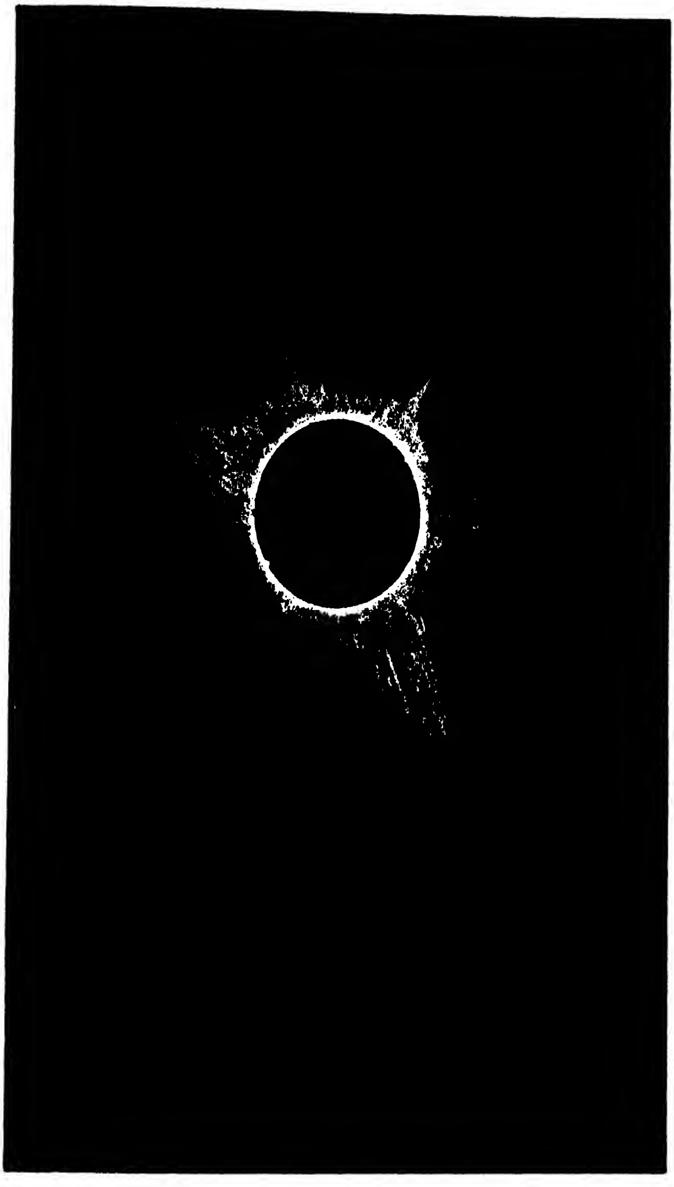
ERRATA.

PLATE II.—For 10th Section read 10th Second.

PLATE III.

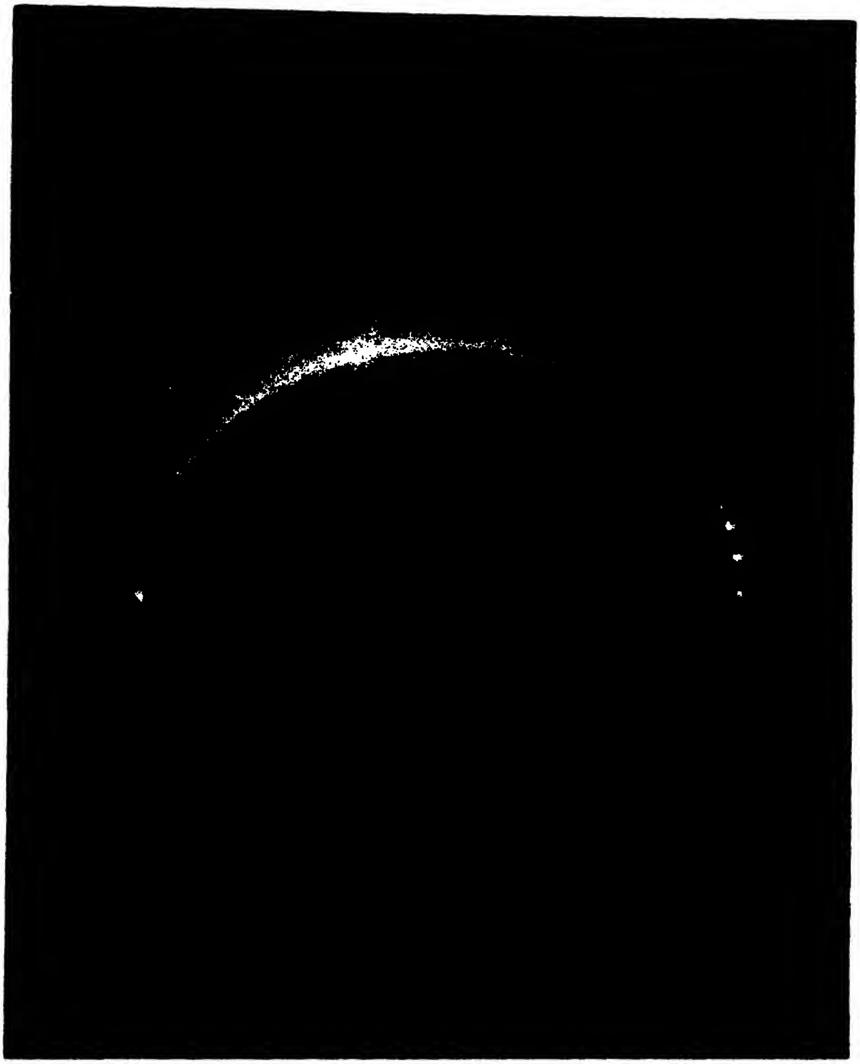
The Observers' Camp, at the Bhojpur Bungalow, Dumraon.

PLATE IV.



The Corona, from a Drawing by the Rev. F. Peal, S.J.

Plate V

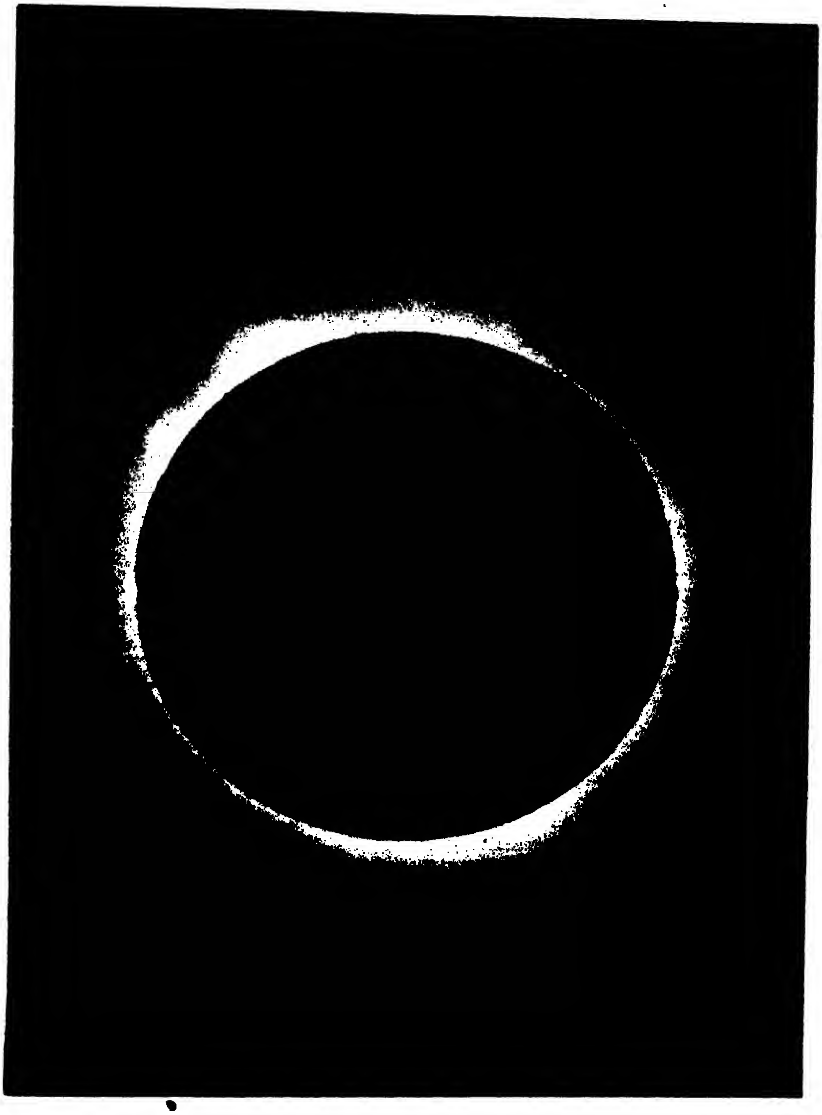


The Inner Corona, at the Time of First Internal Contact

PLATE VI.

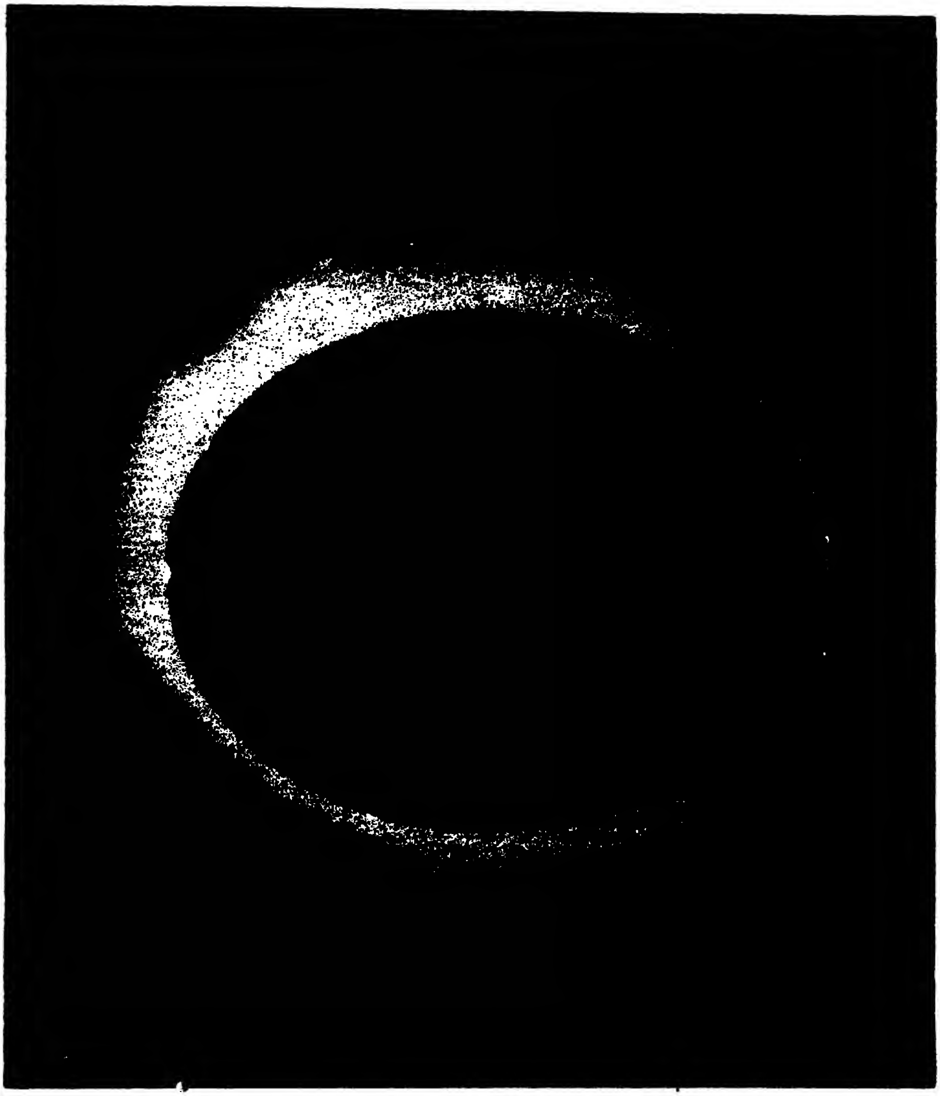
The Outer Corona, at the time of First Internal Contact.

PLATE VII.



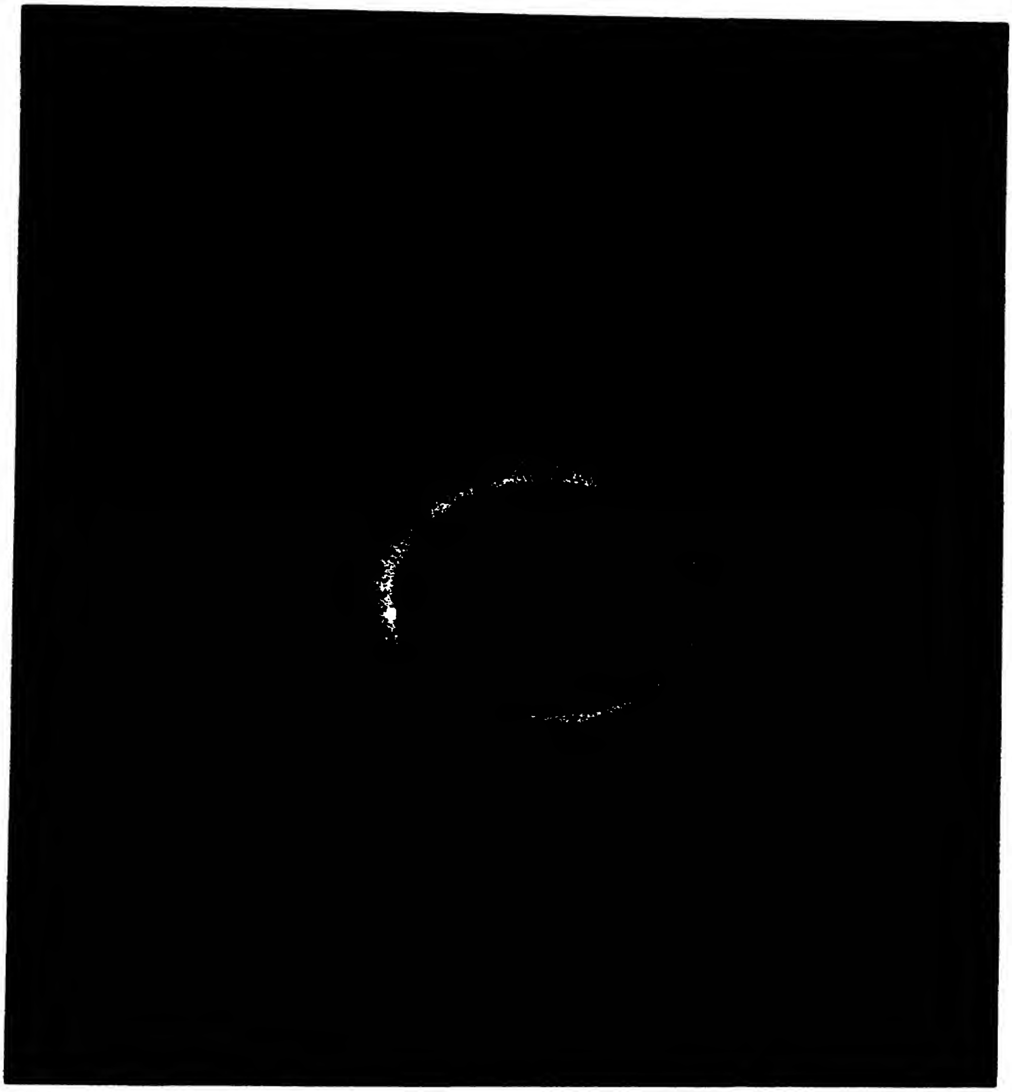
Radiating Structure of the Inner Corona.

PLATE VIII.



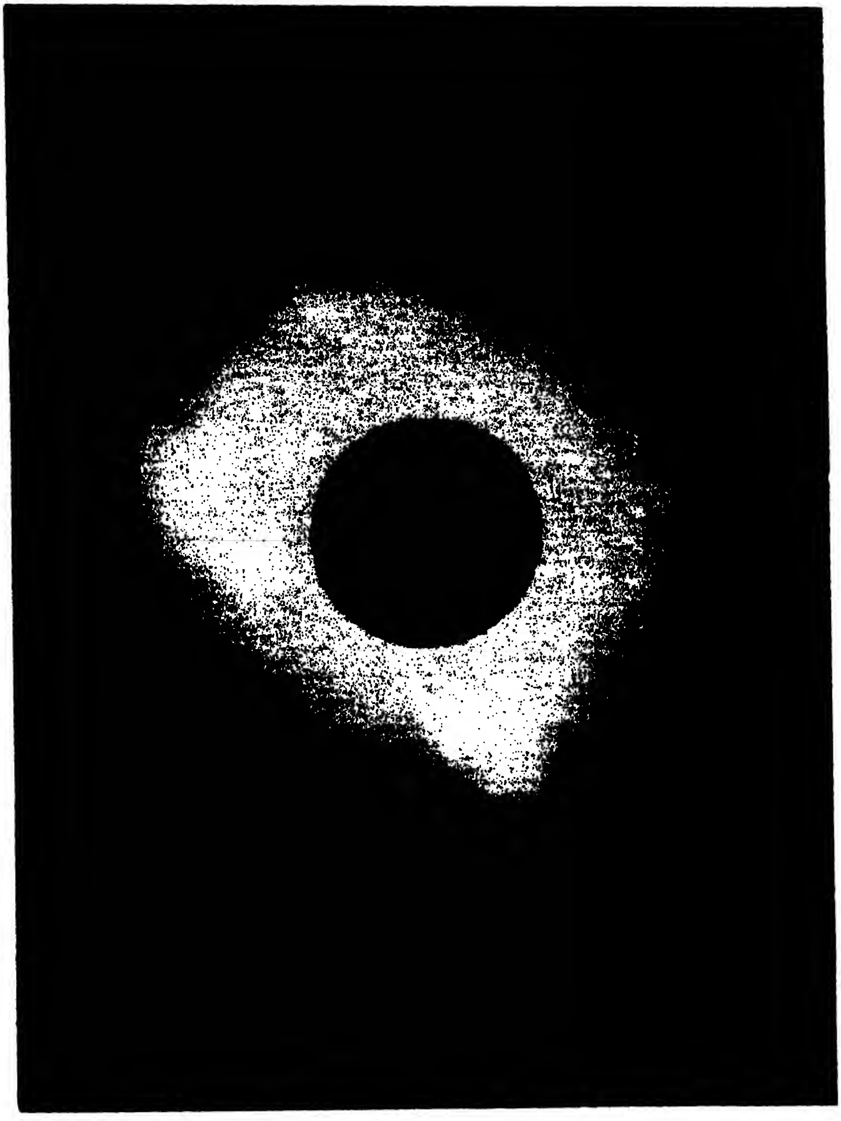
Radiating Structure of the Outer Corona

PLATE IX.



Relative Actinism in the Rays and Streamers, in the Inner Corona.

Plate X.



Relative Actinism in the Rays and Streamers, in the Outer Corona.

PLATE XI.

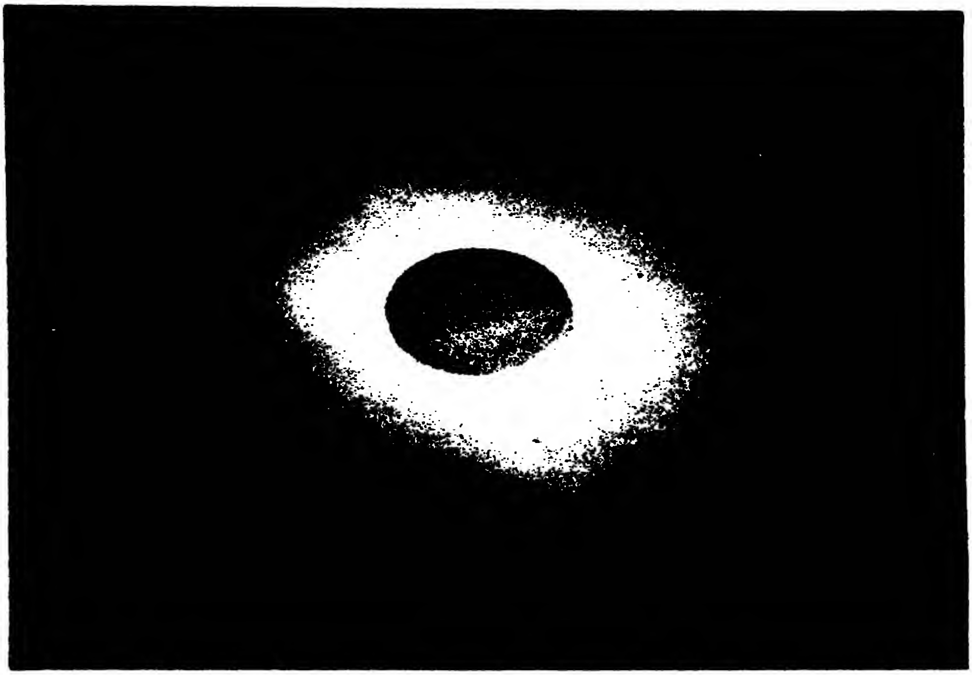


Fig 1. *The Corona, 10 Seconds after the End of Totality.*

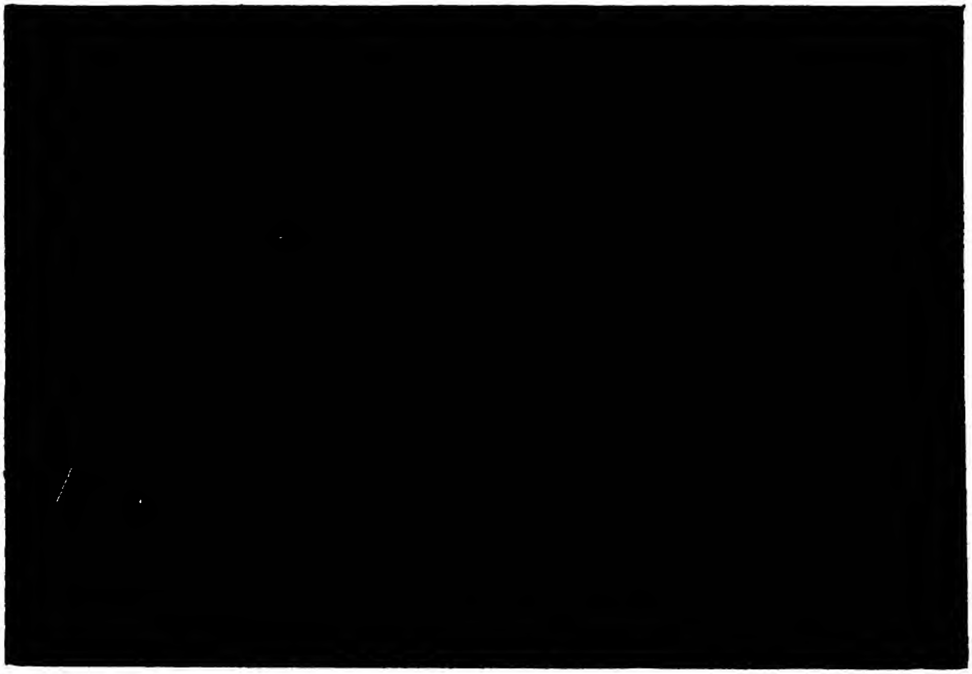


Fig. 2. *Baily's Beads, 13 Seconds after the End of Totality.*

Plate XII.

Fig. 1. *The Solar Spectrum, 1 Second before the Beginning of Totality.*

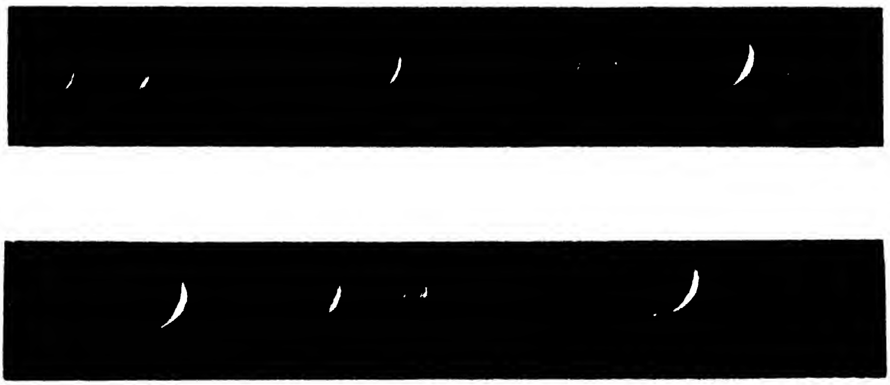


Fig 2. *The Solar Spectrum, 2 Seconds after the Beginning of Totality.*

Fig. 3. *The Solar Spectrum, at the 43rd Second of Totality.*

PLATE XIII

Fig 1. *The Calcium K and H Arcs.*

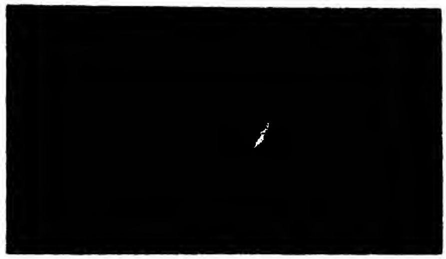


Fig 2. *The Calcium Blue Arc.*

Fig 3. *The Hydrogen Hδ Arc.*

Fig 4. *The Hydrogen Hγ Arc.*

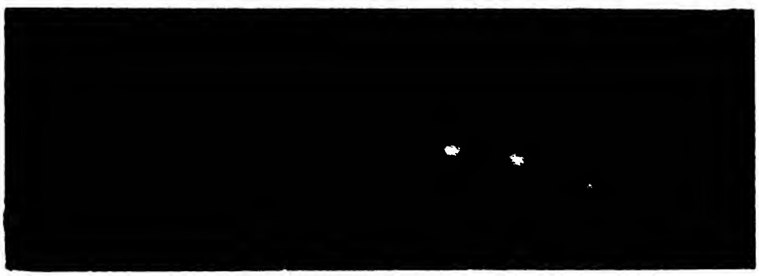


Fig. 5. *The Western Group of Prominences, at the 10th Second of Totality.*

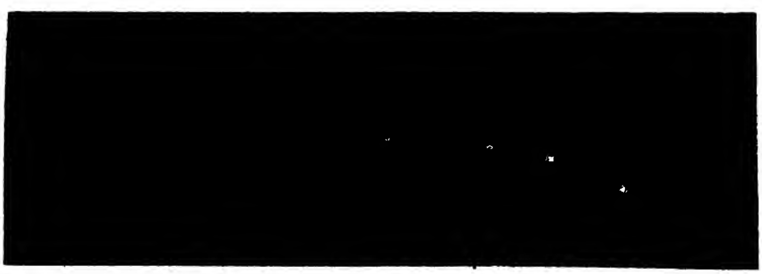
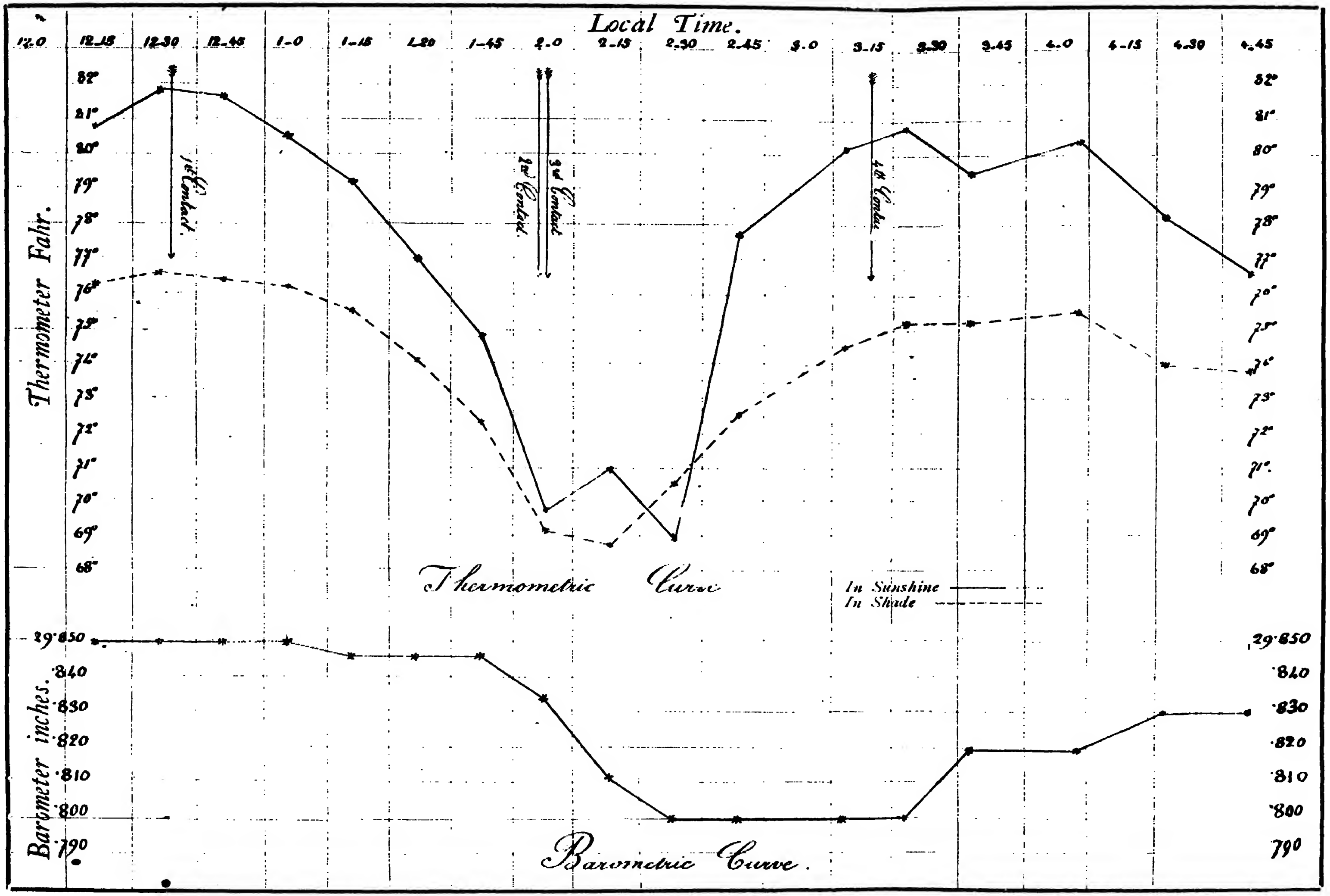


Fig. 6. *The Western Group of Prominences, at the 71st Second of Totality.*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Thermometer Fahr.
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1st Contact.
2nd Contact.
3rd Contact
4th Contact
Thermometric Curve
In Sunshine
In Shade
Barometer inches.
29·850 ·840 ·830 ·820 ·810 ·800 ·790
Barometric Curve.